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COST-EFFECTIVENESS OF ALTERNATIVE TRANSPORTATION FUELS IN URBAN BUS OPERATIONS

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COST-EFFECTIVENESS OF ALTERNATIVE TRANSPORTATION FUELS IN URBAN BUS OPERATIONS

PREPARED FOR:

Efficiency and Alternative Energy Technology Branch
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EXECUTIVE SUMMARY

Objectives

The purpose of this study was to determine the incremental costs and environmental benefits associated with implementing alternative fuels in urban bus fleets in major Canadian cities. Transit fleet operations were examined from the perspective of converting from the use of regular diesel fuel to one of the following fuels during normal fleet replacement:

- low-sulphur diesel with an exhaust particulate trap
- methanol
- natural gas
- gasoline

The specific objectives of the study were to:

- Identify the incremental costs associated with the conversion to, and operation on, an alternative fuel;
- Compare the cost-effectiveness of the alternative fuels in reducing regulated emissions during vehicle operation;
- Compare the cost-effectiveness of a fleet's operation on an alternative fuel with stationary emissions controls;
- Estimate the emissions released during fuel production; and
- Determine carbon dioxide emissions during vehicle operation and fuel production.

Major Findings

The study found that the greatest improvements in emission reductions will be made by fleets switching to newer technology diesel engines as required to meet 1988 emissions standards. The potential reductions for a city such as Vancouver are 8000 tonnes at about $150/tonne. This reduction compared with 4000 tonnes reduction at about $5000/tonne for the most optimistic scenario using an alternative fuel. The study also found that the projected costs of emissions controls for stationary sources may be lower than the use of alternative fuels on a cost per tonne basis.

With respect to the analysis of the alternative fuels, the study found that cost-effectiveness is highly dependent on assumptions about passenger loading due to weight considerations and the projected emission profiles of specific engine-fuel types.

If passenger carrying capacity is reduced by the additional weight of the alternative fuel and fuel tanks, the costs of natural gas and to a lesser extent methanol are very high. In each case, extra buses are required to make-up the reduced carrying capacity of individual buses. These extra buses also contribute to increased emissions. If weight restrictions are resolved through changes in bus design, fuel storage or fleet operations, then the costs of natural gas and methanol will be much less.

Conclusions

The following are the study's conclusions for each alternative fuel assuming weight does not limit carrying capacity:

Particulate traps

The cost per tonne is prohibitively high because of the assumption that only particulate matter would be reduced. Other reasons include the increased price of low-sulphur fuel, increased fuel consumption and the cost of the particulate trap. Long-term durability and reliability of a trap system still have to be demonstrated.

The use of catalysts in conjunction with particulate traps was not assessed in the study. Some research is taking place in this area but there is little published data. If the proper technology could be developed at a reasonable cost ($5,000 - $8,000 per vehicle), a particulate trap - catalyst system could be a reasonable alternative.

Methanol

Using emissions profiles for engines that have been operated in the field, total emissions increase due to more CO emissions relative to diesel engines. However, these CO emissions from methanol engines are within regulated emissions standards. It should be noted that the study treated each regulated emission equally and did not try to assess the relative merits of reducing one emittant in relation to another. Improved engine emissions, based on current research engines produce net reductions in emissions in the order of 4000 tonnes during the period under consideration in the City of Vancouver. The estimated cost is $5000/tonne. Results are similar in other cities. The cost of the methanol option is relatively high due to the price of the fuel. Fuel costs could drop by 40-50% if a large 10,000 metric tonne per day plant were built in Canada to serve the California market. However, the earliest time frame for this scenario would be around the year 2000. Methanol would then be more attractive as an alternative fuel at a cost of about $1500 per tonne of reduced emissions.

Natural Gas

Natural gas is the most attractive fuel from a cost point of view if weight concerns are not an issue for a fleet or if weight restrictions could be resolved through changes in bus design, natural gas storage or fleet operations. Natural gas is very attractive to a fleet owner if fuel taxes are considered in the costs. A city such as Vancouver could realize a savings of $19 million from a conversion to natural gas through savings in fuel taxes. Savings in other cities depends on fleet size and mileage.

The natural gas alternative using currently available engines has a problem with high NOx emissions that exceed regulated standards. This problem is greatly reduced with the latest engines being developed for field use. It does appear that even more advanced engine design will be needed to provide net emissions reductions relative to diesel fuel.

Gasoline

As anticipated, the conversion to gasoline is both costly and results in increased emissions due primarily to CO. This alternative is not being actively pursued by industry. Instead, production and availability of heavy duty gasoline engines is decreasing as demand decreases.

Fuel Production and Carbon Dioxide Emissions

The study also examined fuel production emissions. The study found that emissions during methanol production partially offset CO and NOx gains during fleet operation by 50% and 25% respectively. For natural gas, gasoline and diesel, fuel production emissions were less than 10% of fleet emissions.

With respect to CO_2 from vehicle operation and fuel production, gasoline is the largest source while natural gas produces the least (about 30% less than gasoline). CO_2 from low sulphur diesel and methanol are comparable at a level of about 17% above natural gas.

RÉSUMÉ DE DIRECTION

Objectifs

L'étude avait pour but de déterminer les frais supplémentaires ainsi que les bienfaits environnementaux associés au remplacement des carburants utilisés par les parcs de transport urbain dans certaines grandes villes du Canada. On a examiné l'aspect opérationnel du réseau de transport public dans le contexte d'effectuer le remplacement du carburant diesel ordinairement utilisé par l'un des carburants énumérés ci-après lors du renouvellement normal des véhicules.

- diesel à faible teneur de souffre avec système d'échappement muni d'un piège à particules

- méthanol

- gaz naturel

- essence

L'étude avait pour buts précis:

- de déterminer les frais supplémentaires associés à la conversion au remplacement du carburant et au fonctionnement à partir de ce carburant;

- de comparer la rentabilité des carburants de remplacement en ce qui a trait à l'élimination des émissions faisant l'objet de reglementation lors du fonctionnement du véhicule;

- de comparer la rentabilité de fonctionnement d'un parc de véhicules consommant un carburant de remplacement à l'aide de méthode de contrôle d'émissions fixes;

- d'évaluer les émissions causées par la production de carburant; et

- d'examiner les émissions de dioxyde de carbone produites au cours du fonctionnement des véhicules et celles qui proviennent de la production du carburant.

Principales constatations

L'étude a mis en évidence que le fait de convertir les parcs à la plus récente technologie touchant les moteurs diesel conformément aux normes d'émissions de 1988 est ce qui permet de réduire le plus efficacement les émissions. L'élimination potentielle pour une ville comme celle de Vancouver est de 8000 tonnes à environ 150 $/tonne. Cette élimination est comparable à une réduction de 4000 tonnes à environ 5000 $/tonnes dans le cas du scénario le plus optimiste élaboré à partir de l'utilisation d'un carburant de remplacement. L'étude a, en outre, démontré que le coût prévu pour le contrôle d'émissions de source fixe peut s'avérer moins élevé que celui qui est encouru lorsqu'on utilise des carburants de remplacement sur une base du coût la tonne.

En ce qui concerne l'analyse des carburants de remplacement, il a été établi que la rentabilité de ceux-ci repose en grande partie sur des hypothèses concernant le nombre de passagers, c'est-à-dire sur un facteur de poids, et sur des profils d'émissions de types précis de carburants et de moteurs.

Si la capacité de transporter des passagers est diminuée par le poids additionnel du carburant de remplacement et des réservoirs qui le contiennent, le coût du gaz naturel, et à un moindre degré celui du méthanol, s'avère très élevé. Dans chacun des cas, on doit avoir recours à d'autres autobus pour compenser la capacité réduite de transporter des passagers. Ces autobus supplémentaires contribuent à leur tour à augmenter les émissions. S'il s'avère possible de régler le problème de limites de poids par des modifications apportées au modèle, au conteneur de carburant ou au fonctionnement du parc, l'utilisation du gaz naturel ou de méthanol ne serait plus aussi coûteuse.

Conclusions

Ce qui suit constitue les conclusions de l'étude pour chacun des carburants de remplacement. Ces solutions sont mises de l'avant dans l'hypothèse que le poids ne diminue pas la capacité de transporter des passagers:

Pièges à particules

Le coût la tonne des pièges à particules est presque inabordable à cause de la supposition que seules les particules seraient éliminées. L'augmentation du prix du carburant à faible teneur de souffre, l'augmentation de la consommation et le coût du piège à particules constituent également d'autres causes. La durabilité à long terme et la fiabilité du système restent à être démontrées.

La possibilité d'utiliser des catalyseurs de pair avec des pièges à particules n'a pas fait l'objet d'examen. La recherche dans ce domaine existe mais il y a peu d'information. S'il était possible de développer une technique appropriée à un coût raisonnable (5000 $ à 8000 $ par véhicule), un système piège à particules et catalyseur pourrait constituer un bon choix.

Méthanol

A l'aide de profils d'émissions pour les moteurs en usage dans le domaine, on a constaté une augmentation du taux d'émissions totales à cause d'un plus haut taux de CO comparativement aux moteurs diesel. Par contre, les émissions de CO des moteurs au methanol demeurent conformes aux normes d'émissions permises.

On doit noter que l'étude traite également des émissions reglementées et ne cherche pas à évaluer les mérites relatifs d'une forme d'émission plutôt que d'une autre. Selon les résultats de recherches en cours, les moteurs améliorés ont permis d'éliminer approximativement 4000 tonnes d'émissions, durant la période considérée pour la ville de Vancouver. Cette réduction représente un coût estimatif de 5000 $/tonne. On a obtenu des résultats semblables dans d'autres villes. Le coût de l'option méthanol est relativement élevé à cause du prix du carburant. Le coût de ce carburant pourrait chuter de 40% à 50% advenant la construction, au Canada, d'une importante usine capable de produire 10,000 tonnes métriques par jour dans le but de desservir le marché Californien. If faut cependant préciser qu'il ne serait pas possible de mettre en oeuvre ce scénario avant l'an 2000 environ. Le méthanol constituerait à ce moment-là un carburant de remplacement plus intéressant et se vendrait au coût de 1500 $ la tonne d'émissions éliminées.

Gaz naturel

Le gaz naturel constitue le plus attrayant des carburants du point de vue coût si, dans le cas d'un parc donné, le poids n'entre pas en ligne de compte ou si les limites dues au poids pouvaient être résolues en modifiant la conception des autobus, le stockage du gaz naturel ou le fonctionnement du parc. Le gaz naturel représente un carburant intéressant pour un propriétaire de parc d'autobus, s'il tient compte des taxes sur le carburant. Une ville comme celle de Vancouver pourrait réaliser des économies de 19 millions de dollars en convertissant ses autobus au gaz naturel et en devenant ainsi admissible à l'exemption de taxes sur le carburant. Dans d'autres villes, les économies reposent sur l'importance du parc d'autobus ainsi que sur le kilométrage.

Les moteurs actuels alimentés au gaz naturel présentent des émissions de NO_x qui dépassent les normes établies. Ce problème est partiellement éliminé lorsqu'il s'agit de nouveaux moteurs mis en circulation. Des moteurs plus avancés sur le plan technologique semblant requis si l'on veut fournir une meilleure élimination des émissions relatives au diesel.

Essence

Comme prévu, la conversion à l'essence est un processus coûteux qui produit davantage d'émissions polluantes principalement à cause des émissions de CO. L'industrie ne s'intéresse activement pas à cette alternative. Au contraire, la production et la mise en marché des moteurs lourds à essence diminue en même temps que la demande.

La production de carburant et les émissions de dioxyde de carbone

L'étude a permis d'examiner les émissions resultant de la production de carburant. C'est ainsi qu'on a déterminé que la production de méthanol produit des émissions qui annulent partiellement les améliorations obtenues au niveau de l'efficacité de la consommation du carburant: de 50% pour le CO et de 25% pour le NO_x. Pour le gaz naturel, l'essence et le diesel, les émissions dues à la production du carburant représentaient moins de 10% des émissions produites lors de la combustion.

En ce qui concerne le CO_2 provenant du fonctionnement des véhicules et de la production du carburant, l'essence en représente la source la plus importante tandis que le gaz naturel en produit le moins (30% moins que dans le cas de l'essense). Les émissions de CO_2 en provenance du diesel et du méthanol à faible teneur de souffre sont comparables et représente un taux de 17% de plus que celles du gaz naturel.

TABLE OF CONTENTS

EXECUTIVE SUMMARY ... i
RESUMÉ ... iv

SECTION **PAGE**

I INTRODUCTION ... 1

- A. BACKGROUND ... 1
- B. OBJECTIVES OF STUDY ... 4
- C. METHODOLOGY ... 4

II IMPLEMENTATION SCENARIO ... 6

- A. TRANSIT FLEET DESCRIPTION ... 6
- B. REVENUE PASSENGERS ... 7
- C. CURRENT ENGINE DESCRIPTION ... 7
- D. BUS AGE AND REPLACEMENT POLICY ... 8
- E. FLEET MILEAGE ... 9
- F. BUS MILEAGE DEPENDENCE ON AGE ... 9

III MAJOR COST FACTORS ... 10

- A. INFRASTRUCTURE ... 10
- B. MAJOR VEHICLE COSTS ... 13
- C. FUEL COSTS ... 26

IV EMISSIONS PROFILE/VEHICLE EMISSIONS ... 29

- A. REGULATED EMISSIONS ... 29
- B. CO_2 EMISSIONS ... 34

V DESCRIPTION OF ANALYTICAL FORECAST MODEL ... 36

- A. GENERAL DESCRIPTION ... 36
- B. SCENARIOS ANALYZED ... 38

VI ANALYSIS OF RESULTS ... 41

- A. INTRODUCTION ... 41
- B. CHANGES IN EMISSIONS ... 41
- C. ECONOMIC AND FINANCIAL COSTS ... 48

TABLE OF CONTENTS

SECTION **PAGE**

VII EMISSIONS PROFILE - FUEL PRODUCTION 52

- A. NATURAL GAS 52
- B. METHANOL 57
- C. PETROLEUM REFINERY 61
- D. SUMMARY 65

VIII COMPARISONS WITH EMISSIONS FROM STATIONARY SOURCES 67

- A. INTRODUCTION 67
- B. GLOBAL PICTURE 67
- C. TOTAL EMISSIONS IN CANADA 67
- D. SULPHUR DIOXIDE (SO_2) 69
- E. PARTICULATES 72
- F. NITROGEN OXIDES (NOx) 73
- G. VOLATILE ORGANIC COMPOUNDS (VOC) 73
- H. SUMMARY 75

IX SUMMARY AND CONCLUSIONS 76

REFERENCES

APPENDICES

A Toronto Star Article On Roadway Damaged Caused By Overloaded Buses
B Detailed Results, Scenario 1 - Vancouver
C Detailed Results, Scenario 2 - Vancouver
D Detailed Results, Scenario 3 - Vancouver
E Detailed Results, Scenario 4 - Vancouver
F Detailed Results, Scenario 5 - Vancouver
G Detailed Results, Scenario 6 - Vancouver
H Detailed Results, Scenario 6: Edmonton, Hamilton, Toronto, Montreal

LIST OF TABLES

		PAGE
I-1	Canadian Anthropogenic Emission Inventory	2
I-2	Heavy Duty Diesel Exhaust Emissions Levels	3
II-1	Transit Fleet Composition By City and Vehicle Type	6
II-2	Revenue Passengers By City	7
II-3	Replacement Age: Policy vs. Practice	8
II-4	Fleet Distance for 1987 Operational Year	9
III-1	Summary of Refuelling Facility Costs	13
III-2	Projected Differences in Vehicles	14
III-3	Vehicle Engines	16
III-4	Summary of Incremental Engine Costs	17
III-5	Existing Transit Fleet Maximum Load Standards	21
III-6	Different Weight of Replacement Engine and Drive Train	22
III-7	Summary of Fuel and Fuel Tank Weight Data	23
III-8	Summary of Incremental Weights	24
III-9	Maintenance Requirements per 52,000 km	24
III-10	Driver and Mechanic Wages	25
III-11	Summary of Fuel Costs	27
III-12	10,000 mtd Methanol Plant Costs (1990$)	28
III-13	Fuel Consumption By Engine and City	28
IV-1	Engine Emission Profile	30
IV-2	Vehicle Emissions Profile	30
IV-3	Advanced Alternate Fuel Engines	33
IV-4	Engine CO_2 Emissions - Vancouver	35
VI-1	Incremental Exhaust Emissions for Scenario 3	44
VI-2	Projected Emissions Reductions with the 6V92TA Engine	47
VI-3	National Incremental Emissions With Alternative Fuels	48
VI-4	Economic Cost Summary	49
VI-5	Low Cost Methanol Fuel	50
VI-6	Financial and Economic Cost Comparisons	50
VI-7	Cost Effectiveness of Alternative Fuels	51
VII-1	Emission From Sweetening Process	55
VII-2	Emission Factors for Field Gathering and Process Plant Engines	55
VII-3	Emission From Field Gathering and Process Plant Engines	56
VII-4	Emission From Natural Gas Processing	56
VII-5	Emission From Natural Gas Processing For the Production of Methanol Fuel	59
VII-6	Continuous Methanol Plant Emissions	60
VII-7	Emissions Released During Methanol production	60
VII-8	Total Emissions from Methanol Preparation	61
VII-9	Module Atmospheric Emissions, Gasoline Refinery (lb/day)	64
VII-10	Gasoline Refinery Emissions	65
VII-11	Process Airborne Emissions	65
VII-12	Fuel Refinery Emissions	66
VII-13	Total Carbon Dioxide Emission	66

LIST OF TABLES (Cont'd)

PAGE

VIII-1 Anthropogenic Sources of Atmospheric Emissions in Canada ref (38) 69
VIII-2 Canadian Sources of SO_2 (37) 71
VIII-3 Summary of Stationary Emissions Abatement Costs 75

LIST OF FIGURES

III-1 Fast Full System 12
III-2 Load Equivalency Factors 19

V-1 Economic and Emissions Forecast Model Outline 36
V-2 Forecast Model Sensitivity Analysis 38

VI-1 Incremental Exhaust Emissions - Vancouver Scenario 1 42
VI-2 Incremental Exhaust Emissions - Vancouver Scenario 2 43
VI-3 Incremental Exhaust Emissions - Vancouver Scenario 3: No Weight Penalty 44
VI-4 Incremental Exhaust Emissions - Vancouver Scenario 4: Research Engines/Weight Constraints 45
VI-5 Incremental Exhaust Emissions - Vancouver Scenario 5: Research Engines/Half Fuel Load 46
VI-6 Incremental Exhaust Emissions - Vancouver Scenario 6: Research Engines/Zero Weight Penalty 46

VII-1 Flow Diagram of Natural Gas Processing 53
VII-2 Flow Diagram of the Amine Process for Gas Sweetening (54) 54
VII-3 The Simplified Natural Gas to Methanol Process 58
VII-4 Simplified Gasoline Refinery Processing Sequence 62

VIII-1 Global Source of Atmospheric Emissions ref (51,52) 68
VIII-2 Canadian Trends in Atmospheric Emissions ref (39) 70
VIII-3 Canadian Anthropogenic Particulate Emissions (39) 72
VIII-4 1980 Ontario VOC Emissions (35) 74
VIII-5 1980 Ontario Anthropogenic VOC Emissions ref (35) 74

IX-1 Summary Fleet Cost-Effectiveness 77

I INTRODUCTION

A. BACKGROUND

In recent years, considerable attention has been focussed on reducing exhaust emissions from motor vehicles. Much of this attention is due to the situation in many large urban centres in the United States where air quality is having a measurable adverse effect on man, animals, vegetation, and materials. While Canadian air quality is better, it is evident that Canada too will inherit the adverse affects of unwanted atmospheric pollutants unless remedial action is taken.

There are two sources of atmospheric pollutants: natural and anthropogenic (man-made). Natural pollutants include hydrocarbons emitted from vegetation, nitrous oxides from lightening, and carbon monoxide from natural sources. Anthropogenic pollutants include both mobile and stationary sources. The internal combustion engine and the fuel used in such engines represent a major portion of the anthropogenic pollution generated in the world, and contributes to the following environmental issues:

- climate change;
- depletion of the stratospheric ozone layer;
- acid deposition;
- photochemical oxidants; and
- other toxic air pollutants.

Even though they represent only approximately four percent of all highway vehicles, the Canadian heavy duty vehicle sector has been identified as a significant contributor of atmospheric pollutants. Table I-1 illustrates the emissions from light and heavy duty vehicles in Canada.

The emissions identified in Table I-1 are known to have adverse effects on human health and the environment. Nitrogen oxide (NOx) emissions can aggravate respiratory problems, contribute to acid precipitation, and create a brownish haze in the sky. NOx and hydrocarbons (HC) will react in the presence of sunlight to contribute to the production of ozone and other photochemical oxidants in the lower atmosphere. Carbon monoxide (CO) is a potentially lethal gas that displaces oxygen in the blood and has adverse effects on fetal development. Diesel particulates are solid constituents that can be inhaled and deposited within the lungs, soil the environment, or reduce atmospheric visibility. Certain constituents within diesel particulates are considered carcinogenic. Notwithstanding the national concern for these undesirable emissions, to make matters worse, the emissions from transportation sources tend to be concentrated in urban areas where their effects can be more pronounced.

Table I-1. Canadian Anthropogenic Emission Inventory

(tonnes x 10^6)

	HYDROCARBONS	CARBON MONOXIDE	CARBON DIOXIDE	NITROGEN OXIDES	PARTICULATE MATTER
Light Duty Vehicles[1]	575	4,694	63,197	464	
Heavy Duty Vehicles[2]	146	1,127	33,490	334	23
Other Transportation	48	250	21,175	188	6
Other Anthropogenic	971	4,737	271,363	954	___
TOTAL	1,740	10,808	389,225	1,941	N.A.

Source: Energy Mines and Resources Canada

Notes:
1. Light Duty Vehicles including motorcycles, passenger cars, and trucks 3855 kg GVWR and less
2. Heavy Duty Vehicles includes trucks over 3855 kg GVWR

To protect the health of Canadians and the environment from damage caused by pollution, the federal government has initiated a number of measures aimed at controlling atmospheric emissions. These measures include:

1. The Montreal Protocol (September 16, 1987): an international agreement that protects the ozone layer by controlling and implementing phase-down requirements for ozone-depleting substances; and establishes a technical base for developing pollution control strategies.

2. Canadian Environmental Projection Act: a federal Act that consolidates the federal environment authority; and establishes tough sanctions against polluters.

3. Toronto Conference on Climate Change: an international conference that called for a twenty percent reduction in CO_2 emissions.

4. Sulphur Dioxide Protocol: an international agreement that called for a thirty percent reduction in sulphur emissions by 1993.

5. Oxides of Nitrogen Protocol: An international agreement to limit NOx emissions to 1987 levels by 1995.

6. Motor Vehicle Emission Standards: under the Motor Vehicle Safety Act (Canada), imposes tougher emissions standards on light duty (Sept 1, 1987) and heavy duty (Dec 1, 1988) motor vehicles.

7. NOx and VOC Control Plan: a federal-provincial agreement to develop a NOx and Volatile Organic Compounds (VOC) control program.

In addition, under the Clean Air Act and the Motor Vehicle Safety Act, the federal government has initiated programs designed to educate the motoring public. It should be pointed out, however, that notwithstanding the federal government initiatives, the responsibility for developing and enforcing in-use vehicle standards is a provincial matter.

Dealing specifically with regulated motor vehicle emissions, Transport Canada has reacted with different sets of emission regulations applicable to light duty and heavy duty motor vehicles. Table I-2 presents current and proposed emission standards applicable to heavy duty diesel engines. Canadian regulations have generally followed U.S. regulations. The State of California, exercises its own regulatory authority. The reason for this departure is linked to the severe air quality problem that exists in certain regions of California.

Table I-2. Heavy Duty Diesel Exhaust Emissions Levels
(gm/kW hr)

Year	Location	HC	CO	NOx	PM
1988	Canada and Calif.	1.7	20.8	8.0	0.8
1988	USA	1.7	20.8	14.4	0.8
1990	USA	1.7	20.8	8.0	0.8
1991-93	USA & Calif.	1.7	20.8	6.7	0.34(1)
				0.13(2)	
1994	USA & Calif.	1.7	20.8	6.7	0.13

Notes: 1. applicable to all engines other than urban bus engines
2. applicable to urban bus engines only

Of concern to vehicle/engine manufacturers are the pending U.S. heavy duty diesel emissions levels. As shown in Table I-2, both the Environmental Protection Agency (EPA) and California have enacted regulations which mandate further curtailment of emissions from this category of engines for 1990, 1991, and 1994. Canada has studied these levels, but has taken no regulatory action to date. The new EPA and California limits are focussed on NOx and particulate emissions, and segment the heavy duty diesel engines between urban transit bus engines and other motor vehicle applications.

To meet tougher standards in the U.S., heavy duty engine manufactures are examining a number of approaches. These include:

- very close injection timing through electronic controls to account for load and speed variations;
- reductions in the sulphur and aromatics components found in diesel fuels;
- treatment of the diesel exhaust using particulate traps or catalytic converter systems;

- design changes in the combustion chamber including variation in compression ratios and higher injection pressures;
- the use of alternative fuels including methanol and natural gas.

One potential method for reducing emissions within the urban core is through the use of an alternative fuel in urban vehicles. Urban transit fleets have been singled out to use alternative fuel because they are one clearly identifiable source of emissions that continually operate within a prescribed zone. In addition, urban bus fleets offer the following advantages for using an alternative fuel:

- centralized maintenance and refuelling facilities;
- operation within a designated area; and
- relative standardization of engine type within a given fleet.

B. OBJECTIVES OF STUDY

The purpose of this study was to determine the costs and environmental benefits associated with using an alternative fuel in urban bus fleets located in Vancouver, Edmonton, Toronto, Hamilton, and Montreal. Transit fleet operations were examined from the perspective of converting from the use of regular diesel fuel to one of the following:

- low-sulphur diesel with an exhaust particulate trap
- methanol
- natural gas
- gasoline

The specific objectives of this study were to:

- identify the incremental costs associated with conversion to, and operation on, an alternative fuel;
- compare the cost-effectiveness of emissions reductions of the selected alternative fuels versus diesel fuel; and
- compare the cost-effectiveness of a transit fleet's operation on an alternative fuel with other forms of atmospheric emissions abatement.

C. METHODOLOGY

The overall approach taken by this study to meet the stated objectives comprised the following major tasks:

1. Development of a profile of the five transit fleets which included the number of diesel buses, types of engines used, fuel consumption, revenue passengers, and vehicle driving distances;

2. Determination of the vehicle replacement schedule for each fleet during which alternative fuelled engines would be introduced;
3. Determination of the mix of new buses to old buses by operational year;
4. Estimating the major incremental capital and operating costs involved in changing to an alternative fuel as compared with the use of diesel-fuelled engines;
5. Calculation of the vehicle emissions profile on a gram per kilometre basis for diesel and alternative fuel engines for each operational year;
6. Preparation and use of an analytical computer model to determine the incremental costs and changes to emissions over the bus replacement cycle for each fleet;
7. Completion of a financial cost model that included all federal and provincial fuel taxes, and a social cost model that excluded tax implications;
8. Calculation of the net present value and the current year value for each cost model;
9. An estimate of the emissions released to the atmosphere at the point of production of the fuels under consideration;
10. Review of the literature on the cost-effectiveness of air pollution abatement in stationary applications;
11. Preparation of a detailed cost-effectiveness comparison of the alternative fuels relative to continued use of diesel and other atmospheric pollution emission abatement procedures.

II IMPLEMENTATION SCENARIO

A. TRANSIT FLEET DESCRIPTION

The "Forecast Model" developed in this study is designed to calculate the incremental exhaust emissions and incremental costs associated with replacing *diesel fuelled buses with units operating on alternative fuels. To give the Forecast* Model specific reference to the Canadian environment, five transit systems were selected for detailed analysis. These systems include Montreal, Toronto, Hamilton, Edmonton, and Vancouver. Collectively, these five systems represent almost fifty-five percent of all urban transit vehicles operated within Canada, and four of Canada's five regions.

While most urban transit fleets are composed of various diesel, electric, subway, and heavy rail vehicles, the Forecast Model only examines the traditional two axle diesel motor bus. Of the cities selected for this study, only Hamilton has articulated buses. The six 1982 articulated units operated by the Hamilton Street Railway Company are included in the Model, but are given the same characteristics as standard 12.2 metre units. The Forecast Model assumes that no existing diesel bus will be replaced with an electric or trolley bus.

The vehicle composition of the transit fleets is illustrated in Table II-1. This data was obtained from the Canadian Urban Transit Association's 1987 Survey of their members. The "Total Canada" figures presented in Table II-1 represent the eighty-six transit systems who are members of CUTA.

Table II-1. Transit Fleet Composition by City and Vehicle Type
(1987 CUTA Survey Data)

Vehicle Type	City					Total Canada
	Vancouver	Edmonton	Hamilton	Toronto	Montreal	
Motor Bus*	596	669	314	1525	1983	10518
Articulated Bus	0	0	6	0	0	6
Trolley Coach	245	100	56	150	0	551
Light Rail	90	37	0	303	0	513
Heavy Rail	0	0	0	634	759	1624
Other	2	0	0	0	0	2
Total	933	806	376	2615	2742	13294

* Most current data available (Vancouver and Edmonton 1989, Hamilton 1987, Montreal and Toronto 1986)

B. REVENUE PASSENGERS

The number of revenue passengers carried by each of the selected fleets, per year, was obtained from the 1986-87 CUTA Operators Survey. The number of revenue passengers includes all passengers on all fleet vehicles, including vehicles which are not diesel buses. Revenue passengers are defined in the CUTA survey as passengers riding one-way from a point of origin to a final destination within the area served by the transit system. As such, passengers who transfer from one transit vehicle to another during a trip are only counted once. The term "Revenue Passenger" includes those persons who are entitled to ride free, such as policemen, postal employees, and transit employees.

Because the Forecast Model is examining the incremental exhaust emissions and the incremental costs, the Model assumes that there will be zero change in the number of revenue passengers carried. This assumption ensures that incremental emissions and incremental costs are directly attributable to the introduction of an alternate fuel rather than a result of growth.

Table II-2 illustrates the revenue passenger data used in the Forecast Model.

Table II-2. Revenue Passengers by City

City	Revenue Passengers
Vancouver	102,000,000
Edmonton	41,766,342
Toronto	456,900,000
Hamilton	28,990,467
Montreal	366,209,210

C. CURRENT ENGINE DESCRIPTION

While precise vehicle descriptions are obtainable for the majority of buses within the selected fleets, the Forecast Model simplifies the calculations by assuming all existing diesel buses utilize the 6V71N engine manufactured by the Detroit Diesel Corporation (DDC) and a drive train manufactured by General Motors (GM). Informed sources estimate this engine is utilized in 85% to 90% of all diesel buses currently used in Canada. The predominate alternative engine utilized in the balance of the buses is manufactured by Cummins.

Amendments to the Canada Motor Vehicle Safety Standards require all heavy duty diesel engines manufactured after December 1, 1988, to meet new, more stringent exhaust emission standards. The result of these amendments is the introduction of a new engine referred to as a DDC 6V92TA (V-6 engine, 92 cubic inches per cylinder, Turbo charged, Air-to-air induction cooling). The older 6V71N engine is no longer available in a configuration which meets the Canadian emission standards.

D. BUS AGE AND REPLACEMENT POLICY

The age at which a bus is replaced and the number of buses replaced each year are two of the principle factors which influence maintenance requirements, the number of spare buses, accumulated exhaust emissions, and accumulated fuel consumption. This is due to two factors. First, older buses require more maintenance, and breakdown more frequently than newer buses. Secondly, greater emission and fuel consumption benefits can be achieved by replacing a bus early in the fleet replacement cycle rather than later in the cycle.

Because the Forecast Model calculates the incremental change in emissions and costs, a baseline fleet must be defined against which future improvements can be measured. As the December 1, 1988, amendments to the exhaust emission standards have already introduced a change to the existing fleet, the Forecast Model defines the baseline as the emissions and costs associated with a transit fleet which is replacing 6V71N engined buses with 6V92TA engined buses over a period of time equal to one bus lifecycle. The incremental costs calculated by the Forecast Model will therefore represent the difference between switching to 6V92TA engines over a period of sixteen to twenty years and switching to an alternative fuel during the same time interval.

Each transit fleet has established a policy for replacing buses according to the vehicle's age. However, the actual practice of replacing buses is largely influenced by annual budgets, changes in ridership, the condition of the current fleet, and so forth. For each of the selected fleets, the policy replacement age was less than the actual practice followed by the operating authority. Table II-3 illustrates the discrepancy between replacement age based on policy and replacement age based on actual practice.

Table II-3. Replacement Age: Policy vs Practice

CITY	SURVEY YEAR	REPLACEMENT AGE	
		POLICY	PRACTICE
VANCOUVER	1989	20	29
EDMONTON	1989	20	29
TORONTO	1986	18	21
HAMILTON	1987	18	20
MONTREAL	1986	16	27

Because the Forecast Model needed a uniform rule for determining which buses are to be replaced and when they are to be replaced, the Forecast Model assumes actual replacement practice follows the fleet's established policy.

E. FLEET MILEAGE

For each fleet, the total number of kilometres travelled during each operational year were used by the Forecast Model to determine fuel consumption and total emissions. The distances travelled by active revenue buses during 1987, illustrated in Table II-4, were obtained from CUTA's 1987 Annual Survey of Member Operating Characteristics. This mileage includes only motor buses and articulated buses in regular passenger service. Deadheading, maintenance, training, and/or auxiliary service kilometres are included in the mileage accumulations.

Table II-4. Fleet Distance for 1987 Operational Year

City	Fleet Mileage (km)
Vancouver	42,388,226
Edmonton	29,180,117
Hamilton	10,850,789
Toronto	99,232,000
Montreal	73,085,612

F. BUS MILEAGE DEPENDENCE ON AGE

In an effort to keep maintenance costs to a minimum, most transit fleets accumulate more kilometres on newer buses than on older buses. Older buses are kept as spare units, or are pressed into service only at peak hours. Of the five fleets examined, only Edmonton attempted to equalize bus mileage amongst all buses regardless of age.

The relationship between bus age and bus mileage is important to this analysis because emissions and fuel consumption are dependent on mileage.

III MAJOR COST FACTORS

A. INFRASTRUCTURE

The introduction of an alternative fuel to an urban transit fleet will not only require changes in the bus units themselves, but will also require changes to the refuelling, maintenance, and garage facilities. The cost of changes to the infrastructure is significant, and under specific circumstances, could exceed the cost of replacing the bus units.

For the purposes of this analysis, a common approach was undertaken to establish the required infrastructure at each fleet location. The approach involved the creation of a "unit facility" capable of handling all refuelling, storage, and bus maintenance requirements. For the purpose of analysis, each "unit-facility" was assumed to consist of:

- refuelling equipment
- garage or storage yard and maintenance shed; and
- all special equipment requirements associated with the use of an alternative fuel.

Each facility was sized to accommodate two hundred vehicles as this is a typical vehicle complement for a Canadian transit garage (1)* Thus, the number of facilities required for any given transit fleet and fuel type is directly proportional to the total number of urban buses at a given time divided by two hundred. The resultant number of facilities is rounded up to the next whole number to ensure there are no fractional parts of a facility (i.e. 2.25 facilities would be rounded up to 3 facilities). In practice, a transit fleet operator will have a minimum critical size before it will consider building additional facilities.

Unit facilities, for a given fuel type, were assumed identical at all locations, with no property or building costs factored in. For example, a facility capable of handling 450 buses in Vancouver would be considered as three unit facilities by the Forecast Model, and each unit facility in Vancouver would be priced identically to a unit facility in Hamilton. This approach is acceptable since an incremental approach was used in the Forecast Model for each location considered. Another assumption used in the Forecast Model was that all new alternative fuelled vehicles went to a specific site.

1. Refuelling Equipment:

Refuelling facilities are sized to provide a fast fill capability for a 200 vehicle complement. Five minutes are allowed as the nominal service/recycle time. It should be noted that transit facilities are continuously seeking methods of reducing the service recycle time. The service/recycle time typically includes simultaneous cash collection, refuelling, fluid levels checks, and interior cleaning. Any overall increase in recycle time will have a significant effect on operating costs given that service and cleaning already consume approximately 24% of the total maintenance time requirements (2). Cities, such as Edmonton and Hamilton, have already implemented a program whereby their vehicles are serviced on a two day interval.

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* Numbers in brackets refer to references in Appendix A.

All methanol, natural gas, and gasoline refuelling activities are assumed to take place outdoors. This will no doubt pose difficulties during the winter months at all locations other than Vancouver. Unless safety issues are addressed and regulations changed, indoor refuelling will not be possible.

For all fuels except natural gas, underground single-wall, cathode protected, carbon steel tanks are assumed to be used. These tanks have an estimated life of 15 years. Experience with the Canadian MILE (Methanol in Large Engine) Program has indicated that this type of tank construction is also suitable for methanol (6). The diesel fuel stations are assumed to use a 0.56 kW (0.75 hp) fuel pump motor and conventional fill nozzle to provide a 65 to 90 litres/min refuelling rate. To accommodate the larger volume of fuel required when refuelling the methanol and gasoline engines, a 1.12 kW (1.5 hp) pump motor coupled to a larger capacity pump has been assumed. This will permit vehicle refuelling times similar to those currently needed to refuel diesel buses. This particular set-up, along with "dry-break" type connection fuelling nozzles and a 225 litres/min flow rate, has been demonstrated in the MILE program. "Dry-break" fuelling can also alleviate some of the safety concerns expressed about vehicle refuelling since the nozzle makes a positive connection to the vehicle filler neck eliminating spills, release of vapour, and over fuelling (7). The use of an increased capacity motor (1.12 kW versus .56 kW) is not expected to significantly affect pumping costs.

Natural gas re-fuelling will be handled by direct compression off a natural gas line as depicted in Figure III-1 (8,9). This arrangement will permit the entire complement of 200 vehicles to be refilled in a time frame similar to that presently employed on the diesel buses. Fast fill is believed to be the optimum solution, but at the heavy price of $3.1 million. This cost includes compressors, an electrical substation, and construction costs. In addition to the capital costs, annual operating costs including compression costs (electrical energy to run the compressor motors), compressor maintenance costs, and staffing costs must be considered. Powerful electrical motors will be required to drive the compressors in order to achieve fast fill. Estimates of power requirements range from 10.5 - 13.25 kW/standard cubic metre (scm)/min. (.4 - .5 hp/scfm) (9). All compressors would be required during peak hours to ensure five minute refills whereas during slack periods, when a fast fill isn't critical, fewer compressors can be used. An added feature of this type of operation is a greater degree of reliability. If one compressor/motor fails, the system can continue to operate, albeit at a slower refill rate.

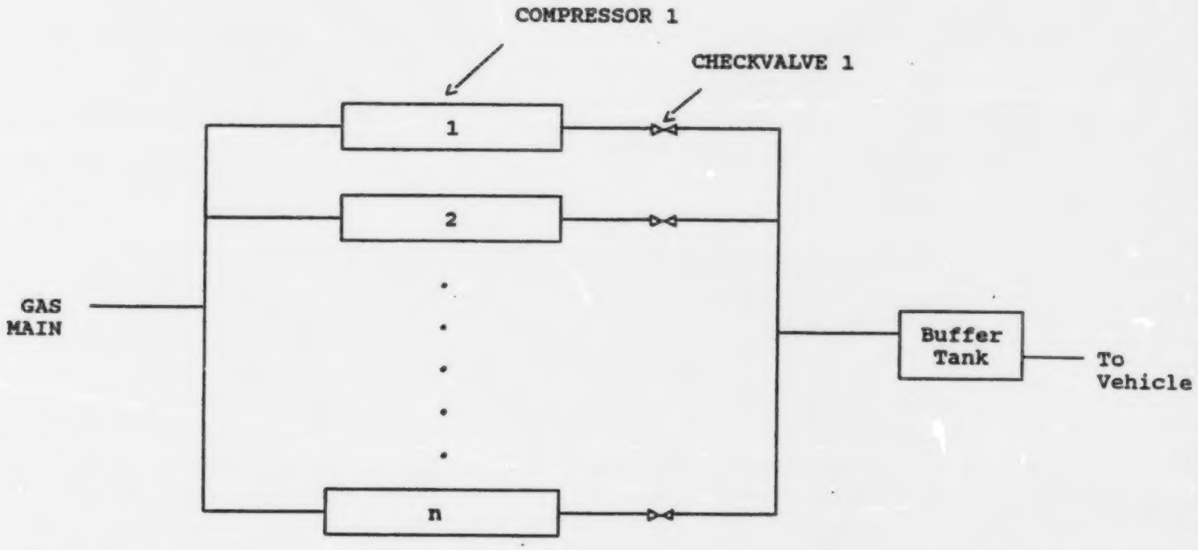

Figure III-1. Fast Fill System

Compressor maintenance is critical in such a system with routine maintenance scheduled on a weekly basis, and major inspections on a biannual basis (9). Typically, maintenance work is arranged for on a contract basis (8,11). Total incremental costs for electricity and maintenance were estimated at 1.24/m3 of gas pumped. These costs were added to the cost of the gas consumed by a transit authority. In addition to the variable incremental costs, a fixed cost of $40,000 per station was assigned for staffing. This allowance was made for a specially trained compressor station operator. Currently, in Ontario, there is no requirement for a stationary engineer to operate the compression station (12).

Table III-1 summarized the costs, by fuel, for constructing a refueling facility.

2. Garage and Maintenance Buildings

As previously noted, the operation of a transit fleet on an alternative fuel will require extensive modifications to all facilities where the vehicles are garaged and maintained. Given that methanol, natural gas, and gasoline are more volatile than diesel, the proposed modifications to the building are required from a safety perspective. These modifications include increased ventilation of vehicle and maintenance areas and upgrades of the electrical equipment to explosion proof/vapour proof fittings in high hazard areas (i.e., where fuel vapours could pool) (4). Using an incremental approach, these costs were

Table III-1. Summary of Refuelling Facility Costs

Per Unit Facility

	DIESEL	METHANOL	NATURAL GAS	GASOLINE
Nominal Storage Capacity	91,000 l	227,000 l	Not Applicable (Pipeline Delivery)	182,000 l
Max Projected Fill Rate	91 l/min	227 l/min	71 m^3/min	227 l/min
Capital Cost ($'000s)	50	195	3,185	175
Useful Life	15 yrs	15 yrs	15 yrs	15 yrs
Incremental Operating Costs:				
Fixed, Per Station	-	-	$40,000	-
Variable			1.2 /m^3	

estimated at an additional $85,000 per unit facility for the methanol, natural gas, and gasoline options at all locations. These costs assume the necessary work will be carried out during the construction phase of the garage or maintenance building. The costs do not include re-engineering and modification of existing facilities. The construction modification costs are scaled towards the low end. Estimates exist ranging from $85,000 to $1.3 million (4,5). These estimates represent extremes from different interest groups.

B. MAJOR VEHICLE COSTS

1. Changes to Engines and Vehicles

A basic assumption of the alternative fuel scenarios is that the appropriate technology has reached commercialization and all vehicles will be built on an assembly line by the coach manufacturer. The assumption concludes that the coach manufacturers will have spread all development costs over a large number of production vehicles, and fleet operators will not incur the costs of acquiring or operating a prototype vehicle.

Design and equipment changes necessary for the alternative fuel vehicles can include a new power train, structural modifications, different fuel tanks, specialized fuel coolers, etc. Table III-2 identifies some of the areas where differences can be expected between an alternative fuelled vehicle and a baseline diesel bus. The table was prepared based on discussions with vehicle manufacturers, a literature review, and MILE program experience. The table is presented in a general form to give the reader an idea of some of the differences, and is not meant to be case specific.

Table III-2. Projected Differences in Vehicles

AREA	PARTICULATE TRAP	METHANOL	NATURAL GAS	GASOLINE
ENGINE/TRANSMISSION MTG.		X	X	X
EXHAUST SYSTEM	X	X	X	X
FUEL SYSTEM		(1),(3)	(2)	(1)
STRUCTURAL		X	X	
FIRE SUPPRESSION (4)	X	X	X	X

NOTES: (1) Increase capacity & material compatibility
(2) Pressurized fuel system
(3) Fuel cooler currently used with DDC & CUMMINS methanol engines
(4) Optional

To create a realistic Forecast Model, five specific engines were examined. These engines represented versions of diesel, methanol, natural gas, and gasoline engines that are currently available. The use of a specific engine enables an emissions profile to be calculated, establishes an engine weight for vehicle passenger capacity, and allows predictions about engine acquisition and operating costs.

All engines, with the exception of the gasoline engine, were selected for use in the Forecast Model based on two criteria:

- the engines have been designed and tested in urban transit buses; and
- emissions and fuel consumption data is available.

These two criteria limit the number of candidate engines, but represent the most likely near-term engines that would be available, and those that would most likely be used. It should be noted that the use of gasoline engines in urban buses has been discontinued. Nevertheless, it was considered worthwhile to include this type of engine in the analysis of emissions and costs.

a) Diesel Engines:

Two diesel engines are used in the Forecast Model analysis. The analysis assumes that all existing transit bus engines are DDC 6V71N. DDC has historically been the predominant transit bus engine supplier in North America. Starting December 1, 1988, all new diesel transit buses manufactured for Canada will likely be the DDC 6V92TA engine. This is the emissions certified engine that DDC is offering to Canada and California in order to meet December 1, 1988, Canadian regulations (20). There are other engine manufacturers, such as Cummins, who also provide a diesel engine which meet the new emission standards.

b) Particulate Traps:

The particulate trap scenario is based on the assumption that a viable particulate trap is available. According to USA EPA requirements, the particulate trap will have to be "service free" for at least 150,000 miles. Under this alternative, particulate traps will be used with DDC 6V92TA engines. The Forecast Model calculates particulate emissions based on a trap efficiency of 75% for particulate matter, with no net effect on gaseous emissions.

c) Methanol Engines:

The methanol engine selected is a modified DDC 6V92TA. This engine was selected because of DDC's current penetration into the North American transit bus engine market and their current high profile involvement with methanol engines in transit buses. The Forecast Model assumes that the methanol engine is available in a commercialized version.

d) Natural Gas Engines:

The Iveco engine, model 8820, was selected as the natural gas engine. Gaseous fuelled Iveco engines have undergone successful operation in a number of transit bus fleets, most notably with the Hamilton Street Railway in the case of natural gas. Similar to the methanol engine, a commercialized version is assumed to be available. It should be pointed out that three natural gas powered Cummins L10 engines are now operating in Canadian transit buses; two in Toronto and one in Mississauga. Similar to the Iveco engines, these engines draw a homogenous air-fuel mixture into the cylinder. Both engines utilize Impco mechanical type fuel systems, however, the L10 engine employs lean burn technology. The current version of the L10 has been termed generation I. Generation II technology for the L10 which will feature an electronic control system and gas injection directly into the cylinder is still under development by Ortech International, TNO and Southwest Research Institute. Generation II technology is still in prototype laboratory configuration and no performance details are being released by Cummins. Chapter IV discusses an alternate scenario with a Cummins L10 natural gas powered engine.

e) Gasoline Engines:

A Ford 7.0 l heavy duty gasoline (HDG) engine was selected. This is currently Ford's most powerful HDG engine (21).

The engines selected are summarized in Table III-3. A potential problem with the natural gas and gasoline engines is the power rating of these two engines, 126 and 144 kW respectively. Current Canadian transit buses use 6V71N engines rated at approximately 138 kW (185 hp) and the 6V92TA, rated at 188 kW (253 hp). A higher rated version of the 6V92TA is available for air conditioned buses (200 kW-270 hp). There is an upward trend in power, particularly in light of the desire for power consuming options such as wheelchair lifts and/or air conditioning. With natural gas engines, an increased power rating is a distinct possibility given interest by the natural gas industry to produce a transit bus engine and recent research by both Cummins and DDC into natural gas powered engines. An opposite trend is occurring with heavy duty gasoline (HDG) engines. Already manufacturers are discontinuing their lines of HDG engines and those that continue to offer such engines are offering less of a selection. This condition has been precipitated by a declining demand for HDG engines. There are few gasoline engines available at high power with a heavy duty rating. Increasingly, fleets are turning towards heavy duty diesel (HDD) engines (14,15). GM and Navistar no longer produce HDG engines because of the limited demand (16,17).

Table III-3. Vehicle Engines

SCENARIO	ENGINE	APPLICATION
Diesel-baseline	6V71N	Predominant N.A. urban transit bus engine
Diesel-Post 1988	6V92TA	Certified Cdn. engine (Dec. 1 1988) to replace 6V71N.
Diesel with particulate trap	6V92TA	Assume post-1988 engine with trap.
Methanol	6V92TA	Presently used in demo's: Cdn (MILE), NY (Triboro), Calif (Riverside)
Natural gas	Iveco #8820	Hamilton (HSR)
Gasoline	Ford 7.0L	Currently available HDG engine

A summary of price estimates for the alternative power vehicles, based on an estimate of the incremental costs of moving from a standard diesel powered transit bus with a 6V71N engine to an alternate are presented in Table III-4. Incremental costs for the methanol and natural gas engine, as well as the particulate trap will be volume sensitive. The costs shown in Table III-4 reflect a conservative estimate for limited production. These three products and even the associated alternate fuel systems are now produced on an extremely limited basis. While the DDC methanol engine is OEM supplied, all natural gas engines are presently outfitted by second party sources. It is anticipated that if sales of alternative fuel engines were anywhere near those of today's HDD engines, both methanol and natural gas engine prices would approach those of diesel engines. Also natural gas engines would likely be OEM produced (45).

Table III-4. Summary of Incremental Engine Costs

SCENARIO	ENGINE $	FUEL SYSTEM $	EXHAUST SYSTEM $
Post-1988 diesels	$ 3,000	-	-
Methanol	6,000	2,000	-
Natural Gas	5,000	16,000	-
Gasoline	(5,000)	1,000	-
Diesel w/Particulate trap	3,000	-	5,000

REF (18,19,21,22,23)

The basic price of an entire bus is assumed to be $172,000 based on an Ontario Bus Industries (OBI) 12.5 x 2.6 metre, two axle bus with standard seating and a 6V71N diesel engine.

The incremental costs for a vehicle, shown in Table III-4, is based on the differential price between a vehicle equipped with a 71 series engine and the selected alternate fuelled engine. The incremental vehicle cost associated with a particulate trap is based on an estimate from an exhaust system manufacturer (22). Incremental methanol vehicle costs are based on predictions made by General Motors to a Joint Hearing before the Fossil and Synthetic Fuels and the Energy Conservation and Power Subcommittees in the U.S. in 1984 for production engines (18). At those hearings, GM predicted an incremental price of between $6,000 to $7,000 for production between 250 to 300 buses per year. These costs have been corroborated by DDC. Natural gas vehicle costs were based on interviews with OBI and Ortech International (23,45). The gasoline engine option is the only case that shows a net reduction in vehicle costs. These costs are solely attributable to the lower cost of the power plant and the associated drive train.

2. Changes in Vehicle Weight

(a) Payload Capacity

A bus is like any other vehicle. It has a maximum payload capacity beyond which safety, maintenance, and/or performance may be compromised. The introduction of an alternative fuel to the vehicle fleet will likely be accompanied by weight considerations. If the base weight of a bus increases, its passenger carrying capacity (i.e., payload capacity) may decrease. In the case of methanol and natural gas, the weight of the fuel and the fuel tank is considerable. For gasoline, although the weight of the fuel must increase to maintain the same driving range, this additional weight is more than compensated for by the lighter gasoline engine and power train. Even the exhaust particulate trap proposal has a weight consequence, albeit rather minor.

The payload capacity of a bus is a major cost consideration. If payload capacity is reduced, the number of buses needed to provide the same level of service to carry passengers must increase. More buses not only add to the capital costs of purchasing the buses, but also add to the cost of supporting infrastructure, mechanics, and drivers. More buses result in higher fleet fuel consumption, which also increases expenses.

Three factors must be considered when determining maximum vehicle weight:

- the design capacity of the chassis, axle, brakes, tires, wheels, suspension, and steering;
- the capacity of the road bed on which the bus operates; and
- the physical space available to accommodate passengers within the passenger compartment.

These three factors are discussed in the following paragraphs:

Design Capacity:

Under the Canada Motor Vehicle Safety Standards, every vehicle manufacturer must establish a Gross Vehicle Weight Rating (GVWR) which is not greater than the capacity of the axles, brakes, steering, suspension, tires, or rims. The GVWR represents the maximum weight of the vehicle with full fuel, all installed options, driver, and passengers. The GVWR must be prominently displayed above the driver's station on the manufacturer's Statement of Compliance.

The difference between the GVWR and the weight of an empty bus with full fuel and coolant (the Tare or Curb Weight) represents the carrying capacity of the vehicle. In the case of urban buses, since no cargo or luggage is carried, this would be the maximum weight of passengers plus the driver.

For determining compliance with the Canada Motor Vehicle Safety Standards, the standards have established 70kg as the weight of each passenger and the driver. It is therefore possible to calculate the maximum passenger loading allowed while remaining within the manufacturers GVWR.

Some provincial jurisdictions have also established maximum passenger loadings for private and commercial buses, however this study assumes that the provincial standards are not more rigorous than the federal standards.

Roadway Capacity:

Just as the vehicle's brakes, tires, and chassis have maximum design limits, so does the roadbed. Road pavements are flexible structures which are designed to carry certain numbers, types, and weights of axles during its useful life. When a vehicle exceeds the design limits, pavement life is shortened and maintenance requirements increase.

Recently, the Toronto Star reported that the City of Toronto estimated the annual damage to municipal roadbeds caused by overloaded transit buses exceeded one million dollars. (See Appendix B).

To determine pavement loads, the common practice is to convert the load imposed by each axle to a common denominator, referred to as an 80 kN single axle load or 1 Equivalent Single Axle Load (ESAL). This is accomplished by utilizing a load equivalency factor as illustrated in Figure III-2. Note that the load equivalency factor does not increase linearly in proportion with axle loading. Figure III-2 shows this relationship to be roughly exponential to the fourth power (i.e. increasing the axle load two fold will increase pavement stress sixteen fold).

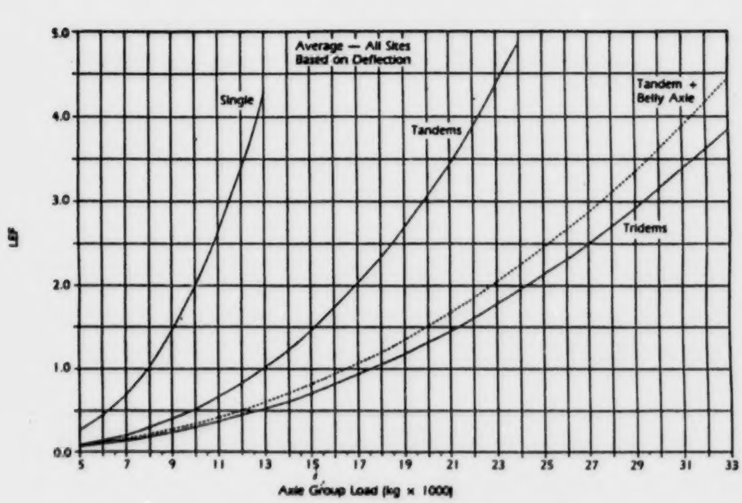

Figure III-2. Load Equivalency Factors

Because of this relationship, provincial governments have imposed strict axle load limitations. For a single axle, this limit is 9,100 kg, less if single tires are used. Generally speaking, the maximum weight of a conventional two axle bus is 15,100 kg; 9,100 kg for the rear axle plus 6,000 kg for the front axle. A bus loaded to this condition would have a load equivalence factor of approximately 4.9.

Using the worst case scenario, a 12.2 m natural gas fuelled bus loaded with 94 passengers might impose a load of 18,000 kg (10,303 kg Tare Weight, + 1,234 kg fuel and tanks + (70 kg x 94 passenger) + (70 kg x 1 driver)). Assuming the load is split 60/40 between the rear and front axles, the axle-loads would be 10 800 kg rear - 7,200 kg front. The load equivalence factor would then be 8.9. Thus, a 20% increase in the load on the axles results in a 80% increase in road bed stress.

Size of Passenger Compartment:

In the Canadian urban bus industry, there are several recognized conventions for determining passenger capacity, including:

i) "crush load" based on the number of passenger seats plus one passenger per .139 m^2 (1 1/2 sq ft). of aisle (not including step wells).

ii) "European .125" - based on the number of passenger seats plus one passenger per .125 m^2 of aisle.

iii) "European 7" - based on the number of passenger seats plus one passenger per .143 m^2 (7 passengers per sq metre). of aisle.

iv) "German 10" - based on the number of passenger seats plus one passenger per .100 m^2 (10 passenger per sq. metre). of aisle.

v) "comfort" - based on 1.5 times the number of passenger seats.

vi) "ellipse" based on the number of seats plus the number of 60.9 x 45.7 (2 ft x 1 1/2 ft) ellipses which can be laid out within the aisle.

Canadian bus manufacturers typically used the "comfort" loading calculation for determining axle loadings in their product promotion.

The transit companies do not, as a rule, follow those conventions and have developed operational standards which are unique to their fleet.

Table III-5 illustrates a number of different operational standards used by transit fleets to calculate their maximum passenger loadings.

Table III-5. Existing Transit Fleet Maximum Load Standards

City	Headway	Seated*	Standees*	Comments**
Vancouver	more than 60 minutes	not specified	0	
	60 "	42	0	
	30 "	47	0	
	20 "	52	0	
	15 "	52	5	
	12 "	52	10	
	less than 12 minutes	52	16	if posted speed on route exceeds 70kmph, maximum standees not to exceed 10.
Edmonton	peak hrs.	52	26	
Calgary	all hours	52	25	
Winnipeg	peak hrs.	52	26	
Mississauga	local service	52	26	
Toronto	peak-hours	52	42	buses typically have 39 to 45 seats, and allow 36 standees. (190% of seated load).
Montreal	peak hours	52	43	
Quebec	peak hours	52	31	

* based on 12 metre bus with 52 passenger seats

** maximum standees based on Gross Vehicle Weight is typically 26 passengers.

b) Forecast Model Weight Inputs

In reviewing current urban bus designs and operating practices, the capacity of roadway appears to be the limiting factor. The Forecast Model therefore calculates passenger capacity as the difference between the curb weight of the bus and the maximum roadbed load. The maximum allowable roadbed load is assumed to be 15,100 kg.

The following values were used as input data to the Forecast Model:

i) Gross Vehicle Weight Rating of 15,100 kg

- based on provincial regulations which allows a 9,100 kg rear axle load and a 6,000 kg front axle load.

ii) Curb Weight of 10,260 kg

- based on MCI Classic because it has the lowest curb weight, thus allowing the greatest passenger load.
- curb weights obtained from other bus manufacturers include: OBI ORION - 10,930 kg; Flyer - 11,004 kg; OBI - 102" - 11,226 kg (with Cummins engine and ZF transmission) - 11,453 kg (with 6V71N engine and GM Transmission).

iii) Incremental Power Train Weight

- based on the weight differential between the 6V71N engine with matching GM transmission and the replacement engine and transmission package.

Table III-6. Different Weight of Replacement Engine and Drive Train

Replacement Engine	Fuel	Differential Weight*
6V92TA	Diesel	+43 kg
6V92TA-PT	Low Sulphur Diesel	+43 kg
6V92TA-M	Methanol	+43 kg
IVECO MDL 8820	Natural Gas	-92 kg
Ford HD Gas	Gasoline	-350 kg

* Compared to DDC 6V71N with matching GM transmission.

iv) Incremental Exhaust System Weight

The incremental weight of the particulate trap was added for the Low Sulphur/Particulate Trap Scenario. The value of 45kg is based on preliminary weights suggested by ORTECH (who are working on a dual filter design) and by Donaldson Company Inc. (who are working on a design using the same principle).

v) Incremental Fuel and Fuel Tank Weight

Conventional fuel tank capacity for a diesel bus is typically 454 l (100 Imp Gallons). This provides the bus with a range of about 900 km based on a fuel consumption of 50 l/100 km.

Not only do the alternative fuels considered by the Forecast Model have different densities, but the weight of the fuel tanks, particularly for natural gas, and the fuel consumption rates vary.

Therefore, except for natural gas, the incremental weight of the fuel and fuel tanks was calculated so as to provide the bus with a range equivalent to diesel fuel. In the case of natural gas, the range was reduced to approximately 600 km in keeping with the current Toronto natural gas bus demonstration program.

For the natural gas case, the Toronto natural gas bus demonstration agreement apparently calls for 457.2 cubic metre (16,000 cu ft) of natural gas which gives the bus a 675 km range based on 66.8 m^3/100 km consumption. The weight of these tanks and the fuel was determined from the initial bus supplied to the Toronto Transit Commission by Ontario Bus Industries, which has a weight of 1,277 kg more than an equivalently equipped diesel bus. The figure of 1277 kg includes the weight for the engine, fuel tanks and fuel.

Table III-7. Summary of Fuel and Fuel Tank Weight Data

Fuel	Specific Gravity	Average Fuel Consumption 1/100 km	Required Volume (Litre)	Range (km)	Wt. Fuel & Tank (kg)	Incremental Wt. Fuel & Fuel Tank (kg)
Diesel (6V71N)	.841	56.8	454	800	381	0
Diesel (6V92TA)	.841	56.1	454	800	381	0
Methanol	.792	125.9	1007	800	797	415
Gasoline	.800	86.8	695	800	556	175
Natural Gas		66.8(m^3/100km)	457(m^3)	600	1,615	1,234

vi) Other Additional Items

Some transit fleets have installed a 520 kg wheel chair lift, a 420 kg air conditioning unit, and/or 225 kg cantilevered seats into the bus. Other weight penalty options include special entrance - exit doors and kneeling suspensions. While the Forecast Model can account for these items, they have not been included for the five selected fleets.

Table III-8 summarizes the incremental weights relative to existing buses used in the Forecast Model. Table III-8 also includes the reduction of passenger payload capacity in terms of displaced passengers due to the increased curb weight of the bus. These values are used in the Forecast Model for estimating the number of buses required to replace existing diesel buses. Where payload capacity is reduced, more buses may be required to carry the same volume of passengers. The Forecast Model also includes analysis that excludes this constraint.

f) Maintenance Requirements

The Booz Allen Evaluation of Vehicle Diagnostics Systems (2) contains the results of an in-depth analysis of maintenance costs by subsystem, in which they conclude that the data they obtained for the Mississauga Transit System was representative of other operations in Canada. Table III-9 identifies the data which the Forecast Model assumes to be correct for each city. The major systems that are relevant in the analysis of alternative fuels are primarily the Fuel and Engine Systems.

Table III-8. Summary of Incremental Weights

Component	Fuel				
	Diesel (6V92TA)	Particulate Trap	Methanol	Natural Gas	Gasoline
Engine & Power Train.	43	43	43	43	(350)
Exhaust Sys.	-	45	-	-	-
Fuel & Tank.	-	-	415	1234	175
Total	43	98	458	1277	(175)
Number of displaced passengers/ bus @ 70kg each.	.6	1.4	6.5	18.2	(2.5)

Table III-9. Maintenance Requirements per 52,000 km

Subsystem	Part Cost	Labour (hrs)
Road Call		0.0
Service/Cleaning		108.0
■ Daily Service		36.0
■ Refueling Increment		0.0
■ Major Interior Clean		36.0
■ Chassis Wash		36.0
Bus Inspections	$ 100	74.2
Body Repairs	$ 850	66.0
Engine & Fuel System	$ 380	50.7
Braking System	$ 1,580	41.4
Electrical System	$ 960	33.8
Transmission	$ 900	27.4
Suspension/Steering	$ 450	20.3
Wheels/Tires	$ 90	14.3
Cooling System	$ 400	14.0
Heating/Ventilation	$ 420	9.9
Compressed Air	$ 540	9.5

In the case of the particulate trap/low sulphur fuel options, the "Engine and Fuel System" parts and labour costs were increase by 10% to reflect the additional parts and labour needed to inspect and repair the particulate trap system. This system is expected to have an 464,000 km life.

In the case of methanol, the "Engine and Fuel System" costs were increased 7% to reflect the additional parts and labour needed to repair injection nozzles, glow plugs, and the associated fuel pumps. Engine rebuilds and replacements are assumed to match the diesel engine baseline. A major assumption is made that DDC can resolve its current injector problems.

For natural gas, the Engine and Fuel System costs were increased 20% to reflect the additional costs of inspection, pressure testing, and replacing the natural gas fuel tanks. These tanks operate up to 3,000 psi. Current regulations require them to be hydrostatically tested once every five years, and replaced after twenty years*. The engine itself is assumed to last 500,000 km, or possible longer.

Both the 6V71N and the 6V92TA engines are assumed to require rebuilds after 500,000 km of service, and no replacement over the entire bus lifecycle.

In the case of gasoline, because both the engine and transmission are less rugged then their diesel counterparts, the total maintenance cost of the bus is assumed to increase 7%. This 7% variance was added to the Engine and Fuel Systems category. The gasoline engine life is expected to be 250,000 km - only half that of a diesel engine. The gasoline engine might, in fact, be a throw-away engine.

g) Wages and Benefits

Although the Forecast Model will accept gross employment expenses, for drivers and for mechanics, the specific cities studied only had wage data available. Table III-10 illustrates the wage data used in the Model.

Table III-10. Driver and Mechanic Wages

City	Driver Wages	Mechanic Wages
Vancouver	16.53	18.94
Edmonton	16.04	18.20
Hamilton	16.02	17.34
Toronto	16.02	17.62
Montreal	15.24	16.89

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* It has been suggested that acoustic testing, which is already acceptable for bulk transportation tanks, may be approved for smaller cylinders by 1990. The twenty year replacement requirement is subject to revision in light of new information and experience.

C. FUEL COSTS

1. Diesel, Gasoline, and Natural Gas

Fuel prices for diesel, gasoline, and natural gas are based on price forecasts supplied by the Transportation Energy Branch, EMR Canada (24). Prices for natural gas assume industrial rate pricing. Unleaded gasoline prices use rate increase predictions for leaded gasoline. Low sulfur diesel fuel costs are predicted based on an expected price premium of 2.9 cent/litre (1990$) with respect to diesel fuel (25). Methanol price predictions are outlined in a subsequent section.

Fuel prices are presented on both a before tax and after tax basis. The before tax figure, used in the economic analysis, is the road pump price less all applicable federal and provincial taxes.

Both gasoline and diesel are subject to federal sales and excise taxes whereas federal taxes on natural gas are waived (26). A federal sales tax rate of 13.5% (effective June 1, 1989) is used in the Forecast Model. Federal excise tax of 8.5 ¢/l* for gasoline and 4.0 ¢/l for diesel were used in price calculations.

In the four provinces considered, provincial road sales taxes are levied on gasoline and diesel. Only the Province of British Columbia levies a tax on natural gas for industrial use. That rate is currently at 0.24 cents/m^3 (24). All fuel price forecasts used in this report assume a constant tax rate over the 20 year evaluation period.

Fuel price forecasts are presented in Table III-11 by city and year. All prices are in 1990$ and it is assumed that there are no price differentials within a province. A uniform bulk purchase price discount of 11% for diesel and low sulfur diesel, and a 13% discount for gasoline was factored into the price calculations for all regions (34). In practice, bulk price discounts will be subject to quantity purchased and region. Natural gas prices are shown with a 1.24 1/m^3 surcharge for compression costs and maintenance.

2. Methanol Fuel Costs

Unlike the other alternative fuels considered, existing methanol production and pricing has been geared towards the chemical market.

The Forecast Model is based on an assumption that fuel would be supplied from existing suppliers, such as Celanese Canada or Novacor Chemicals. The fuel would be transported via conventional means; rail tank car to Toronto, Montreal, Hamilton, and Vancouver, and then by road transport for local delivery to the refuelling station (27). The base price of methanol was established on the basis of factory gate price and transportation costs. Although the volume of methanol that would be absorbed by a transit fleet is relatively small, methanol could be discounted from its present chemical market price (28). There is interest by Canadian methanol producers to develop a stable domestic demand. Methanol costs are based on factory gate price of 15 ¢/litre. Future price increases in methanol were modelled to be influenced by the price of natural gas in Alberta, however, the price component of natural gas represents only approximately 1/3 the plant gate price of methanol (28). Delivery charges were assessed at 6 ¢/litre for rail tank car delivery from Alberta to Eastern Canada and approximately 0.3 ¢/litre to Vancouver. Local delivery was assessed at 1 ¢/litre in all cities. Currently, only federal sales and excise taxes are levied on methanol. Provincial sales tax will be applicable in the provinces of British Columbia and Quebec (29, 30, 31, 32,). Ontario and Alberta do not tax alcohol based motor vehicle fuels, or the alcohol portion of blended fuels.

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* The April 1989 federal budget scheduled the unleaded excise tax to increase to 7.5 ¢/litre from 6.5/litre. As of Jan 1/1990, the federal excise tax is scheduled to increase to 8.5 ¢/litre.

Table III-11. Summary of Fuel Costs

		Before Tax Costs (1990$)			
		Van	Edm	To & Ham	Mtl
Diesel (c/l)	1989	26.0	23.4	26.4	28.7
	1990	25.9	23.4	26.3	28.7
	1995	31.7	29.2	32.1	34.1
	2000	32.2	29.8	32.7	34.6
	2005	32.9	30.6	33.4	35.2
Lo Sulfer Diesel (c/l)	1989	28.9	26.3	29.3	31.6
	1990	28.8	26.3	29.2	31.6
	1995	34.6	32.1	35.0	37.0
	2000	35.1	32.7	35.6	37.5
	2005	35.8	33.5	36.3	38.1
Methanol (c/l)	1989	17.0	16.7	23.0	23.0
	1990	16.3	16.0	22.0	22.0
	1995	21.1	20.8	26.8	26.8
	2000	21.8	21.5	27.5	27.5
	2005	22.4	22.1	28.1	28.1
Nat.Gas (c/m3) with pumping costs	1989	9.8	6.7	13.2	14.9
	1990	9.6	6.9	12.9	14.6
	1995	14.7	12.4	17.6	19.3
	2000	15.9	13.5	18.3	20.1
	2005	17.1	14.6	19.2	20.9
Gasoline (c/l)	1989	27.4	24.5	23.5	25.9
	1990	27.4	24.4	23.5	25.8
	1995	33.0	30.2	29.2	31.3
	2000	33.7	30.8	29.8	31.9
	2005	34.5	31.6	30.5	32.5

		After Tax Costs (1990$)			
		Van	Edm	To & Ham	Mtl
Diesel (c/l)	1989	43.9	35.7	43.8	48.8
	1990	43.5	35.3	43.1	48.0
	1995	48.0	39.4	46.3	50.3
	2000	47.5	38.6	44.7	48.3
	2005	47.2	38.3	43.6	46.9
Lo Sulfer Diesel (c/l)	1989	46.8	38.6	46.7	51.7
	1990	46.4	38.2	46.0	50.9
	1995	50.9	42.3	49.2	53.2
	2000	50.4	41.5	47.6	51.2
	2005	50.1	41.2	46.5	49.8
methanol (c/l)	1989	23.1	19.0	26.1	29.8
	1990	22.2	18.2	25.0	28.6
	1995	28.8	23.7	30.5	34.9
	2000	29.7	24.4	31.2	35.7
	2005	30.5	25.1	31.9	36.5
Nat.Gas (c/m3) with pumping costs	1989	10.1	6.7	13.2	14.9
	1990	9.8	6.9	12.9	14.6
	1995	14.9	12.4	17.6	19.3
	2000	16.1	13.5	18.3	20.1
	2005	17.2	14.7	19.2	20.9
Gasoline (c/l)	1989	51.5	41.3	49.0	52.5
	1990	52.0	41.6	49.0	52.4
	1995	55.4	44.8	50.6	53.6
	2000	54.3	43.4	47.9	50.6
	2005	53.6	42.5	45.8	48.4

A second methanol price scenario was examined. Under this scenario, a large size methanol plant located in Edmonton and capable of producing 10,000 metric tonnes per day was assumed to be available (33). The plant would be geared towards producing methanol for the fuel market in California.

Based on predicted investment and operating costs reported in the California methanol study, and using the local Alberta price of natural gas and a rate of return of 15% over 25 years, the predicted plant gate cost of methanol is $0.10/litre. Table III-12 presents predicted costs, both before and after taxes, in 1990 dollars for the five transit fleets. The above scenario makes the assumption of pipeline delivery to Montreal and Toronto/Hamilton at 1 ¢/litre as opposed to 6 ¢/litre for rail transport (27).

Table III-12. 10,000 mtd Methanol Plant Costs (1990$)

	Fuel Costs cents/l			
	Van.	**Edm.**	**To/Ham.**	**Mtl.**
Pre Tax Cost	11.4	11.1	12.1	12.0
Post Tax Cost	15.5	12.6	13.8	15.7

3. Fuel Consumption

Vehicle fuel consumption will vary among the different fleets due to operational differences between the fleets. Current diesel fuel consumption is available for all fleets under consideration. This data represents for the most part, operation on the 6V71N engine and was used as the baseline data. It is expected that operational differences between the fleets will remain constant, thus the fuel consumption rates for the alternative fuels can be calculated relative to diesel for each fleet. To predict vehicle fuel consumption with the alternative fuels, the percentage difference in specific fuel consumption (sfc) relative to diesel was used. For methanol and diesel, current data on sfc for the 6V71 and 6V92TA engines were used to adjust individual fleets for road fuel consumption. For the natural gas engine, the ratio of natural gas to diesel fuel consumption reported by Hamilton Street Railway was used in conjunction with the reported diesel fuel consumption for the various cities to predict the natural gas consumption of the other fleets. Gasoline engine fuel consumption results were the most difficult to predict since gasoline engines are no longer used on urban transit buses in North America. Fuel consumption was predicted based on the percentage difference typically seen between diesel and gasoline in school buses, which was found to be 50%. Table III-13 summarizes the calculations.

Table III-13. Fuel Consumption by Engine and City

CITY	6V71NA (l/100 km)	6V92TA (l/100 km)	6V92TA w/ PT (l/100 km)	6V92TA w/ Meth (l/100 km)	w/ NG (m3/100km)	w/ Gasoline (l/100 km)
Vancouver	51.02	47.81	50.86	113.12	66.84	76.53
Edmonton	55.87	52.35	55.69	123.87	73.18	83.80
Hamilton	59.17	55.44	58.98	131.19	77.51	88.76
Toronto	54.64	51.20	54.47	121.16	71.58	81.97
Montreal	63.29	59.30	63.09	140.33	82.91	94.94

IV EMISSIONS PROFILE - VEHICLE EMISSIONS

A. REGULATED EMISSIONS

1. Methodology

Heavy duty engine emissions are reported on a specific weight basis (g/MJ in Canada) in order to ascertain engine compliance with federal standards. When examining the emissions contribution from a fleet, emissions on a weight per distance travelled basis is more applicable. The emissions factor procedure, as documented by the EPA, was used to predict vehicle emissions on a weight per distance basis for all fleets (42). Briefly, this procedure generates an emissions factor (EF) which is a function of engine specific fuel consumption (SFC), vehicle fuel consumption (VFC), and fuel density.

$$EF = \frac{\text{Fuel density}}{(SFC)*(VFC)} \qquad \text{eq'n 1}$$

where:

EF is measured in kW hr/km
Fuel is density measured in gm/l
SFC is measured in gm/kW hr
VFC is measured in km/l

The EF is used to convert engine dynamometer emissions results to a weight per distance value.

$$\text{Emission}_i: = EF*DE_i \qquad \text{eq'n 2}$$

where:

Emission_i = emissions of constituent i in gm/km
DEi = emissions recorded on engine dynamometer of constituent i in gm/kW hr

A standard fuel density was used for each fuel and this value was held constant over the fleet lifecycle time span. Engine SFC results are based on published results and are assumed constant over the fleet lifecycle. Vehicle fuel consumption results have been adjusted as previously detailed in Section III-C.

Engine dynamometer emissions results are based on transient HDD test cycle results for diesel and methanol. Emissions results for the natural gas engine are based on engine performance testing carried out over the advanced design bus (ADB) cycle by ORTECH and subsequent in vehicle fuel consumption reported by Hamilton Street Railway (HSR) (43,44). The gasoline engine emissions profile uses the 1991 engineering objective for an electronic fuel injection (EFI) version of the 7.0 litre engine (41). Tables IV-1 and 2 summarize engine and vehicle emissions values.

Table IV-1. Engine Emission Profile

	engine	HC [g/kW hr]	CO [g/kW hr]	NO$_x$ [g/kW hr]	Part. [g/kW hr]	sfc [g/kW hr]
DIESEL	6V71N	0.47	7.96	11.26	0.61	0.300
DIESEL	6V92TA	0.99	1.78	6.81	.45	0.281
METHANOL	6V92TA	1.03	12.08	1.70	0.11	0.593
NG	IVECO	2.14	1.70	22.92	0.04	0.243
GASOLINE	FORD	2.01	38.87	5.36	0.11	0.377
1988 DIESEL STANDARD		1.74	20.78	8.04	0.80	-

(1kW hr = 3.6 MJ = 1.34 hphr)

Table IV-2. Vehicle Emissions Profile

City	Engine		EF (kW hr/km)	HC (g/km)	CO (g/km)	NOx (g/km)	Part. (g/km)
Vancouver	DIESEL	6V71NA	1.4276	0.67	11.37	16.08	0.87
	DIESEL	6V92TA	1.4275	1.42	2.54	9.72	0.64
	DIESEL	w/partic	1.4326	1.42	2.54	9.72	0.16
	METHANOL	6V92TA	1.5159	1.56	18.31	2.58	0.16
	NG	IVECO	1.8305	3.93	3.12	41.96	0.07
	GASOLINE	FORD	0.4188	0.59	7.98	2.55	0.06
Edmonton	DIESEL	6V71NA	1.5632	0.73	12.45	17.60	0.96
	DIESEL	6V92TA	1.5630	1.55	2.79	10.64	0.70
	DIESEL	w/partic	1.5630	1.55	2.79	10.64	0.18
	METHANOL	6V92TA	1.6599	1.71	20.05	2.83	0.18
	NG	IVECO	2.0044	4.30	3.41	45.94	0.08
	GASOLINE	FORD	0.4586	0.64	8.74	2.80	0.06
Hamilton	DIESEL	6V71NA	1.6557	0.78	13.18	18.64	1.01
	DIESEL	6V92TA	1.6555	1.64	2.95	11.27	0.75
	DIESEL	w/partic	1.6555	1.64	2.95	11.27	0.19
	METHANOL	6V92TA	1.7581	1.81	21.23	2.99	0.19
	NG	IVECO	2.1230	4.55	3.61	48.66	0.08
	GASOLINE	FORD	0.4857	0.68	9.25	2.96	0.07
Toronto	DIESEL	6V71NA	1.5291	0.72	12.18	17.22	0.93
	DIESEL	6V92TA	1.5289	1.52	2.73	10.41	0.69
	DIESEL	w/partic	1.5289	1.52	2.73	10.41	0.17
	METHANOL	6V92TA	1.6236	1.68	19.61	2.76	0.17
	NG	IVECO	1.9606	4.20	3.34	44.94	0.07
	GASOLINE	FORD	0.4486	0.63	8.54	2.74	0.06
Montreal	DIESEL	6V71NA	1.7710	0.83	14.10	19.94	1.08
	DIESEL	6V92TA	1.7708	1.76	3.16	12.06	0.80
	DIESEL	w/partic	1.7708	1.76	3.16	12.06	0.20
	METHANOL	6V92TA	1.8805	1.94	22.71	3.20	0.20
	NG	IVECO	2.2708	4.87	3.87	52.05	0.09
	GASOLINE	FORD	0.5195	0.73	9.90	3.17	0.07

2. General Assumptions - All Engines

To compute engine emissions over the fleet lifecycle, a number of assumptions are required. First and foremost, the emissions levels for all engines were assumed to be typical of a given engine and constant over its life. This represents a simplifying assumption, but does away with the need for deterioration factors. Deterioration factors were avoided since little data exists concerning methanol and natural gas engines. Furthermore, it was assumed that there was no engine tampering. With tampering it would impossible to predict fleetwide vehicle emissions.

In time, improvements in vehicle fuel consumption and engine efficiency would result in a decrease in regulated exhaust emissions. For the time being, the model assumed that all engines introduced over the lifecycle of the fleet exhibit identical performance. Future fuel consumption improvements will likely come from reductions in rolling resistance (tire technology), vehicle weight reduction, improvements in drive train lubricants, and electronic transmission control (42).

The model also assumes that fuel quality and density stays constant over the duration of the analysis. Equally important, identical fuel is used across the country; i.e., diesel fuel in Vancouver is identical to diesel fuel available in Montreal.

In addition to the above stated assumptions, a number of engines specific assumptions were made.

- Diesel Engines:

  Crankcase and evaporative HC emissions were assumed to be insignificant (42).

- Particulate Traps:

  It was assumed that an efficiency of 75% reduction in particulate matter and minimal effect on gaseous emissions is achieved with a corresponding fuel consumption penalty of approximately 6% (46,47,48).

  No consideration for emissions during trap regeneration was made.

- Methanol Engines:

  No crankcase or evaporative emissions. All hydrocarbon (HC) emissions are reported as organic material hydrocarbon equivalent mass (OMHCE).

- Natural Gas Engines:

  No emissions due to leakage from the vehicle fuel system. All HC emissions as reported as diesel organic material hydrocarbon equivalent mass (OMHCE) and consists primarily of methane based HC's.

- Gasoline Engines:

  No crankcase or evaporative HC emissions

Engine emissions profile is based on the HDG engine transient cycle

Particulate emissions were estimated using established EPA techniques (42).

3. Technological Considerations

Methanol and natural gas engines offer measurable reductions in certain regulated exhaust gas species. The results presented in Table IV-1 and IV-2 illustrate some of the tradeoffs of these engines with respect to diesel engines. For example, while the methanol engine suffers from increased CO emissions, it still meets 1988 Canadian CO levels. Conversely, the natural gas engine exceeds 1988 Canadian NOx levels. Unlike their diesel or gasoline counterparts which are based on well evolved technology, both methanol and natural gas engines are still in their infancy. The Forecast Model examines a 16 to 20 year projection. Given the current fast pace of technological improvements with alternative fuel engines, one can reasonably expect cleaner engines over the timeframe of the model. Thus a second set of vehicle emissions profiles were generated for the methanol and natural gas scenarios. These emissions profiles reflect recent engine emissions improvements made between the initial data compilation and final analysis of this study. The engines selected were the DDV 6V92TA methanol engine and a natural gas version of the Cummins L10 engine. Both these engines were selected because:

- they reflect the most recent engines available for actual field use.
- they are offered by engine manufacturers recognized within the North American urban transit bus market;
- emissions data was available; and
- DDC has publically stated its intention to produce a commercially available methanol version of the 6V92 engine (68).

At the time of writing of this report, however, no actual field data was available. The latest version methanol engine being offered by DDC features an increased compression ratio (23:1) and idling on 3 cylinders. HC emissions (see Table IV-3) from this engine primarily consist of unburned fuel (methanol), which is much less photochemically reactive than either aldehyde or diesel based HC's. Aldehyde emissions are reported to be very low (50). The exhaust emissions are presented based on the engine being equipped with a catalyst. The catalyst provides approximately a 50% and 75% reduction in HC and CO emissions respectively. DDC is currently pursuing a flexible strategy with catalysts. The catalysts available with their engine can be tailored to significantly reduce HC emissions while being less effective on CO emissions, or alternatively, provide substantial CO reductions with less effect on HC. Therefore, depending on the air quality concerns of a particular region, the catalyst can emphasize either substantial HC or CO emission reductions with respect to the baseline engine. Even without a catalyst, engine exhaust emissions levels are still within 1988 Canadian standards and the more stringent 1991 U.S. rules.

The Cummins natural gas engine utilizes generation I technology and is equipped with a catalyst to control HC and CO emissions. The catalyst provides between an 80% to 90% reduction in HC and CO emissions (13,45). While HC emissions from this engine are primarily composed of methane and are therefore photochemically non-reactive, all HC's are included when determining total HC's. The next version of this engine, termed generation II, may achieve emissions compliance without the use of a catalyst. However, this engine is still undergoing laboratory development.

Engine and vehicle emissions profiles for these two engines are presented in Table IV-3. Engine specific assumptions used in the base case scenario are used here too unless otherwise noted. In all likelihood, if a transit fleet were to undertake an alternate fuel engine replacement policy beginning in 1990, either engine discussed in this section, or their improved successors would be available.

The preceding discussion illustrates the rapid pace of technological improvements with alternative fuel power plants. Engine manufacturers are working from a number of directions, including electronic controls, combustion chamber modifications and exhaust aftertreatment to control regulated exhaust emissions. Concurrent with regulated emissions reductions, engine manufacturers are seeking to improve engine component durability and ensure that the overall "engine system" achieves a useful life of 464,000 km with a minimum maintenance interval of 240,000 km. Ideally, emissions improvements can be achieved through engine based improvements. The use of catalysts, particulate traps and other forms of exhaust aftertreatment comprise a potentially weaklink in the chain from a maintenance point of view. Furthermore, packaging of these components inside current bus configurations may pose a problem.

Table IV-3. Advanced Alternate Fuel Engines

Engine Emissions Profile	HC	CO	NOx	PART	SFC
	[gm/kw hr]				[kg/kw hr]
DDC 6V92TA	0.74	0.6	3.1	0.1	0.56
Cummins L10	1.7	0.3	6.0	0.07	0.40

Vehicle Emissions Profile*	HC	CO	NOx	PART	Emissions Factor $[\frac{kw\ hr}{km}]$	VFC
	[gm/km]					
Methanol	1.12	0.97	4.70	0.16	1.52	107.5 $\frac{l}{100\ km}$
Natural Gas	3.19	0.49	11.04	0.12	1.83	66.8 $\frac{m^3}{100\ km}$

Notes:

* Predicted for the City of Vancouver

B. CO_2 EMISSIONS

Under ideal conditions, all the carbon contained in a fuel will be converted to carbon dioxide (CO_2) when the fuel is combusted in air. The combustion process within an engine is not ideal, hence other carbon containing products are formed too, including carbon monoxide, particulate matter, and various forms of partially combusted or oxidized fuel. The mass of these products is small compared to total CO_2 production, but this illustrates the complexity of the combustion process.

In order to predict the CO_2 emissions from the various fuel-engine combinations, a Combustion Model was constructed to predict CO_2 production. The Combustion Model utilized a simplified combustion equation which assumed the combustion process proceeds under the following reaction:

$$(X1)\ FUEL + (X2)\ O_2 + (3.76 * X2)\ N_2 = (X3)\ CO_2 + (X4)\ H_2O + (X5)N_2 + (X6)HC + (X7)CO + (X8)C + (X9)NO_2 \qquad \text{... eq'n 3}$$

where:

(Xi) = moles of a constituent
HC = hydrocarbon in exhaust, assumed to be fuel
CO = carbon monoxide in exhaust
C = particulate in exhaust, assumed to be carbon
NO_2 = assumed as nitrogen oxide (NO_x) component in exhaust

The fuels were modelled as:

diesel: $C_{11}H_{19}$ for both regular and low sulfur (49)
gasoline: C_8H_{17} (53)
methanol: CH_3OH
natural gas: CH_4

CO_2 output was predicted using a carbon balance for equation 3. Input data consisted of exhaust emissions levels of HC, CO, and C, and the vehicle fuel consumption. CO_2 levels, in terms of gm/km vary by fleet location due to differences in vehicle fuel consumption and emissions profile. However the CO_2/Fuel ratio (by weight) will be constant for a given engine-fuel combination. The results presented in Table IV-4 represent an estimate of CO_2 production. Maximum CO_2 production will occur when all the carbon contained in the fuel is converted to CO_2; i.e., zero. level emissions of HC, CO, and C.

Table IV-4. Engine CO_2 Emissions - Vancouver

Fuel	Fuel Engine	CO_2 gm/km	CO_2/Fuel Ratio (kg CO_2/kg fuel)
Diesel	6V71N	1346.3	3.15
	6V92TA	1272.4	3.17
	6V92TA w/particulate trap	1354.3	3.17
Methanol	6V92TA	1202.8	1.34
Methanol	Latest Technology	1169.0	1.37
Natural gas	Iveco	1205.2	2.71
Natural gas	Cummins	1211.08	2.72
Gasoline	Ford 7.0 L	1713.7	3.03

V DESCRIPTION OF ANALYTICAL FORECAST MODEL

A. GENERAL DESCRIPTION

As previously described, the Forecast Model is specifically designed to predict the incremental expenditures and emission consequences which will be incurred during the transition period in which an urban transit fleet is switched to an alternative fuel. As such, it forecasts values for the differences between selected emission control options and a baseline technology. This baseline technology assumes the transit fleet will continue to use diesel fuel and that new vehicles will comply with current (December 1, 1988) heavy duty vehicle exhaust emission standards. The baseline specifically assumes that fleets would replace old buses using the DDC 6V71N engine with new buses using the 6V92TA engine. The study also assumes that passenger ridership will not change, no technological improvements will come on stream and existing diesel buses will not be replaced with electric or trolley buses.

Figure V-1 illustrates the organization of the Forecast Model which is constructed in Lotus 1-2-3 software.

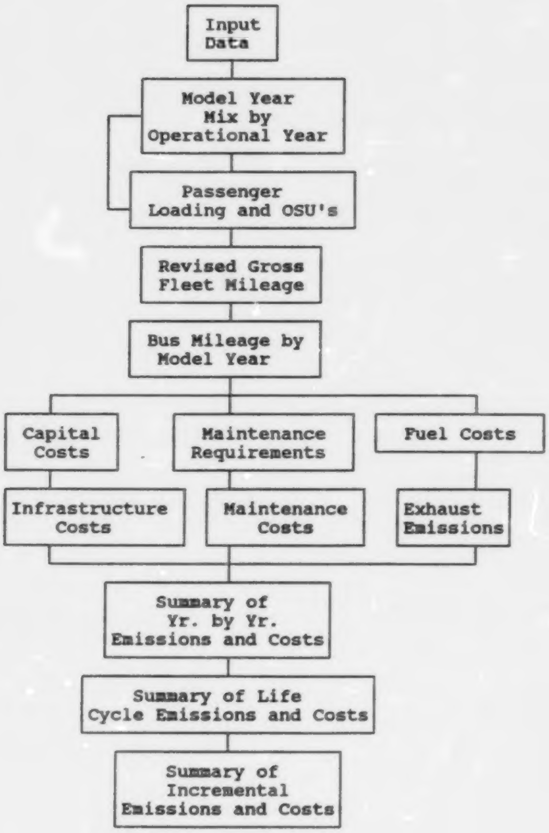

Input Data
Model Year Mix by Operational Year
Passenger Loading and OSU's
Revised Gross Fleet Mileage
Bus Mileage by Model Year
Capital Costs
Maintenance Requirements
Fuel Costs
Infrastructure Costs
Maintenance Costs
Exhaust Emissions
Summary of Yr. by Yr. Emissions and Costs
Summary of Life Cycle Emissions and Costs
Summary of Incremental Emissions and Costs

Figure V-1. Economic and Emissions Forecast Model Outline

Input data consists of variables arranged in six categories: Fleet Description, Vehicle Costs, Infrastructure Costs, Engine Emissions, Fuel Consumption and Price, and Financial. The model tracks the mileage of each model year of bus through each of up to twenty operational years. The Forecast Model considers different utilization rates by operational year based on mileage accumulations (i.e. newer buses are driven more kilometres per year than older buses), escalating maintenance costs based on vehicles age, and changes in future fuel prices. The model calculates passenger loadings based on vehicle capacity and adjusts passenger loads in direct proportion to changes in the vehicle's carrying capacity. The Forecast Model compensates for changes in passenger capacity by increasing the number of buses in the fleet so as to provide zero change in the number of revenue passengers.

The Forecast Model calculates exhaust emissions by exhaust component. These emission calculation rates are based on engine emissions profiles and fuel consumption rates discussed previously.

The Forecast Model calculates the incremental costs associated with adopting an alternative emissions strategy.

The incremental costs are made up of:

- incremental costs incurred by fitting an alternative fuelled engine and associated equipment;
- total cost of additional buses, fitted with an alternative fuelled engine, to recover any passenger shortfalls due to decreased carrying capacity;
- incremental fuel costs;
- total wages for drivers of operational shortfall buses; i.e., extra buses needed to overcome decreased bus carrying capacity;
- incremental wages for mechanics due to changes in maintenance requirements and total wages for mechanics to maintain additional operational shortfall buses;
- incremental costs due to changes in maintenance requirements and total costs for new maintenance, refueling and parking facilities.

The Forecast Model sums up the yearly incremental costs in 1990 dollars over the bus replacement cycle for a fleet. Two cost analysis were conducted. In the financial cost analysis, all Federal and Provincial taxes were included. The net present value of each alternative used a discount rate equal to the average municipal bond rate (currently at 9.4%) adjusted for inflation (projected at 4.3%). The real discount rate was then calculated to be 4.9% using the formula:

$$\text{Real Discount Rate} = \frac{(1 + h)}{(1 + i)} - 1$$

where: h = Nominal Discount Rate
i = rate of inflation

In the economic costs analysis, taxes were excluded. The net present value was calculated using a social discount rate of 7%. To close out the costs analysis, a salvage value was calculated for the last operational year based on a straight line depreciation of the incremental infrastructure and vehicle costs over their respective lifecycles. (15 years for infrastructure, fleet replacement period for vehicles).

Output values are expressed in a number of terms including incremental costs per passenger, per kilometre, per tonne of emissions reduced, and per litre of diesel fuel (or equivalent) consumed.

Special care must be taken in examining the output data as it reflects the differential costs between adopting the alternate fuel and adopting the 6V92TA engine.

B. SCENARIOS ANALYZED

Initial results of the Forecast Model indicated that assumptions about vehicle passenger capacity and vehicle emissions technology where two principal variables that have a major impact on incremental fleet emissions and program costs. Therefore, the Forecast Model was used to analyze a number of scenarios to investigate the effect of these variables in detail. Figure V-2 illustrates the scenarios that were analyzed.

	Weight Constraints	Reduced Fuel Load	No Weight Limitation
Field Demonstration Engines	Scenario 1	Scenario 2	Scenario 3
Research Engines	Scenario 4	Scenario 5	Scenario 6

Figure V-2. Forecast Model Sensitivity Analysis

Scenario 1 - Weight Constraints

In Scenario 1, the Forecast Model was built around the following assumptions:

- maximum passenger load is determined by the difference between the legal axle loading and the curb weight of the bus;
- additional weight imposed by an alternative fuel option will increase the curb weight of the bus, and hence reduce the maximum passenger load;
- current ridership levels remain constant and maximum passenger loadings are achieved during peak hours;

- current fleet schedules can not be adjusted to increase ridership;
- fleet size would be increased to make up the passenger load shortfall brought about as a result of the introduction of an alternative fuel;
- vehicle exhaust emissions are for engines that have been demonstrated in the field and for which there is emissions and operational data; and
- particulate trap technology will be available to meet the 1991 heavy duty engine emissions standards.

Scenario 2 - Reduced Fuel Load

Because the baseline model projects passenger capacity loses due to additional bus curb weight, a forecast was conducted whereby the fuel load was reduced by 50%. In doing so, the cost of the natural gas, methanol, and gasoline fuel tanks were also reduced by a similar percentage to indicate a lower fuel loading. With smaller fuel tanks, the scenario assumed the vehicles would require servicing more frequently, hence incremental refueling time for each fuel was increased by 36 hours for every 52 000 km.

Current diesel buses carry sufficient fuel to give them a range of about 900 km, but in practice, many fleets refuel after 300 to 500 kilometres. The full fuel load of 454 litres (diesel) may not, therefore, by necessary.

The reduced fuel scenario examined exhaust emissions given current demonstration technology and assumed particulate traps are available.

Scenario 3 - No Weight Limitation

A third scenario was conducted with a full fuel load, however, the scenario assumed that there will be no change in the passenger loading of the bus as a result of switching to the alternate fuel. Such a scenario might exist with technology advances in construction techniques and materials such that the curb weight of the vehicle can remain unchanged. For example, composite fuel tanks for natural gas are reported to be 60% lighter than all-steel tanks and 20% lighter than fiber-wound aluminium. This scenario might also reflect those cases where the existing passenger loading is sufficiently below the road bed capacity so as to accommodate the extra weight.

Scenario 4, 5 and 6 - Research Engines

These three scenarios are the same as scenarios 1, 2 and 3 except that the analysis uses different exhaust emissions data for the natural gas and methanol engines. More specifically, the analysis uses available exhaust emissions data for the DDC 6V92TA engine with a 23:1 compression ratio and the Cummin L-10 natural gas engine. At the time of writing of this report, no actual field data was available.

In addition to the six scenarios described above, two other analysis were conducted. Because the December 1988 amendments to the Canadian Motor Safety Standards represent a major step forward in reducing exhaust emissions, we investigated the emissions reductions brought about by the introduction of the 6V92TA engine as a replacement of the older 6V71NA engines typically found in Canadian bus fleets in the past.

Finally, it has been suggested that significant reductions in the cost of methanol could be achieved through the construction of a 10,000 metric tonne per day methanol plant in Edmonton. The plant would be geared towards producing methanol for the fuel market in California. The Forecast Model examines the economic and financial impacts for the Vancouver fleet.

VI ANALYSIS OF RESULTS

A. INTRODUCTION

In the previous chapters, a mathematical Forecast Model was developed to predict the environmental impact and the incremental resources needed to operate a transit system should an alternate fuel technology be introduced. This Forecast Model was constructed so as to evaluate the total consequences accumulated over the entire transitional period during which the alternate fuel technology is being introduced.

Once the Forecast Model was constructed, and relevant input data gathered, different implementation scenarios were introduced to determine the sensitivity of the analysis to various factors, especially: emission characteristics, weight, and fuel costs.

This chapter presents the results of the analysis for the scenarios outlined in the previous chapter. More specifically, this chapter presents the results for the City of Vancouver in detail and for all the fleets in summary form.

B. CHANGES IN EMISSIONS

In each of the following scenarios, the changes in fleet emissions as a result of introducing an alternative fuel are presented. The results shown are the incremental exhaust emissions relative to the baseline technology of the 6V92TA diesel engine.

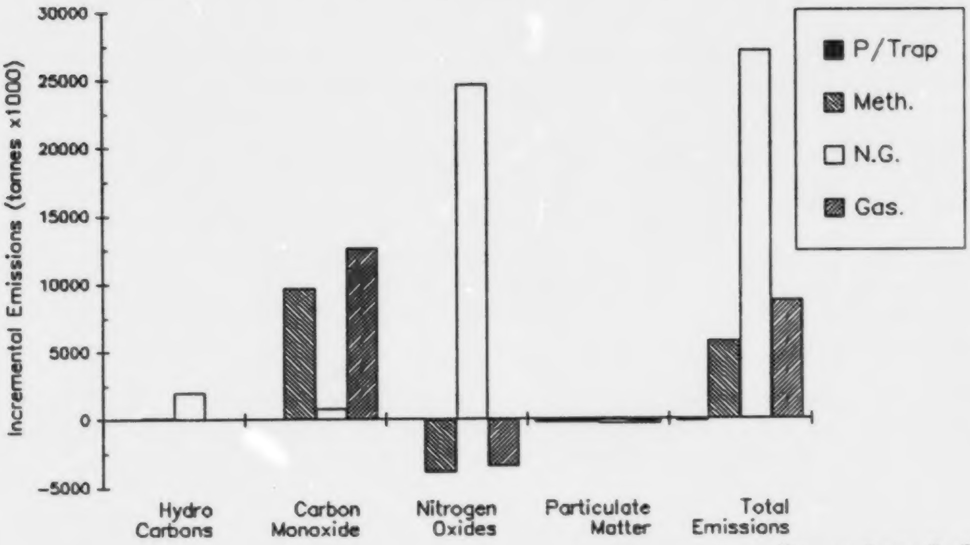
Scenario 1 - Weight Constraints/Field Demonstration Engines

This scenario assumes that there is a maximum Gross Vehicle Weight limitation. Thus, as the curb weight increases, the passenger capacity must be reduced. Similarly, as the curb weight decreases, the passengers capacity is allowed to increase.

As expected, the Forecast Model predicts a change in the total fleet size due to the introduction of alternate fuels. Because a gasoline engine and power train is lighter than the reference diesel unit, passenger capacity per bus increases, thus reducing the total fleet size. For Vancouver, 23 fewer buses would be required for a gasoline powered fleet. At the other extreme, 153 more buses would be required for the Vancouver fleet if powered by natural gas, principally due to the weight of the natural gas fuel tanks. For methanol, 48 additional buses would be required.

Figure VI-1, Vancouver Scenario 1, illustrates the predicted changes in tail pipe emissions.

With the exception of the 6V92TA low sulphur diesel engine fitted with particulate traps, no alternate fuel technology offered total tail pipe emission reductions beyond that projected for the current 6V92TA diesel engine technology. All alternate fuel technologies are expected to reduce particulate matter, and all are expected to increase carbon monoxide. A major contributing factor to the increased emissions is the need for extra buses to overcome shortfalls in reduced carrying capacity.



Source: Appendix B

Figure VI-1. Incremental Exhaust Emissions-Vancouver Scenario 1

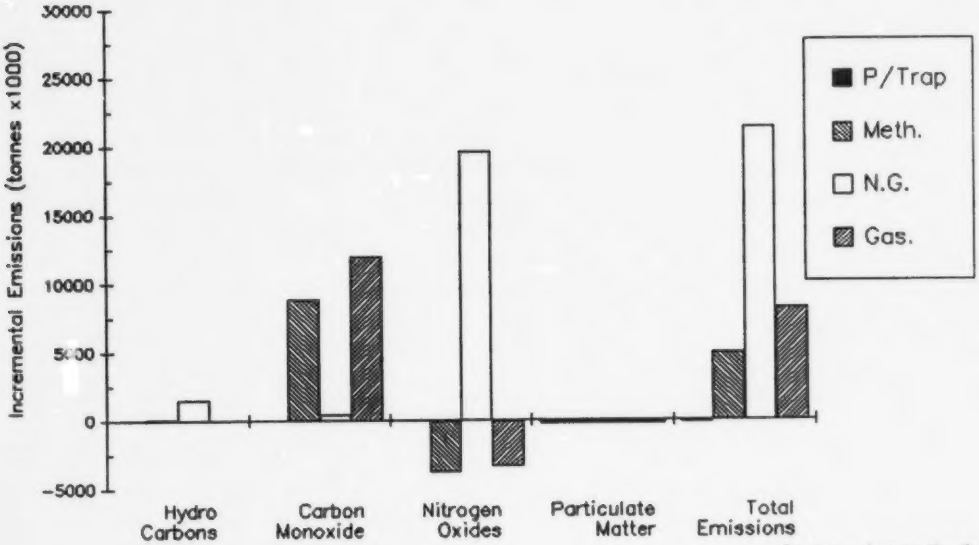
Scenario 2 - Half Fuel Load

Like scenario 1, scenario 2 also assumes that there is a maximum Gross Vehicle Weight limitation, but attempts to overcome this problem by reducing the fuel load by half. Less fuel does reduce the vehicle's range, and requires it to return to the refuelling facility more often.

Reducing the fuel load by half has increased the vehicle's passenger capacity, but not to the extent enjoyed by a bus powered by a 6V92TA diesel engine. Thus more buses are still required than the diesel base case. Hence, as illustrated by Figure VI-2, tail pipe emission levels for scenario 2 are less than predicted for scenario 1, but not significantly so.

Scenario 3 - No Weight Penalty

The next logical step in searching for possible system changes was to assume that through some manufacturing technique or materials development, the curb weight of the alternate fuel technology buses would not change from that currently enjoyed by buses powered by a 6V92TA diesel engine. It is further assumed that these manufacturing and materials changes would not affect the passenger loading.



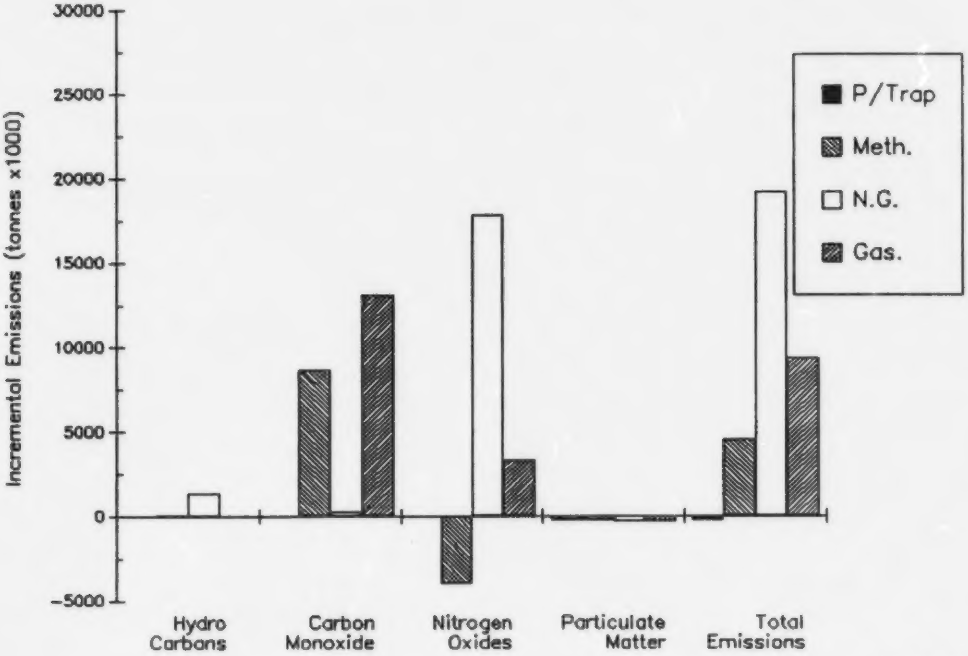
Source: Appendix C

Figure VI-2. Incremental Exhaust Emissions-Vancouver Scenario 2

This scenario also reflects those cases where the existing passenger loading is sufficiently below the legal weight limit or fleets choose to exceed this limit.

Assuming these changes are possible, the change in fleet size, the total fleet miles driven, and changes to tail pipe exhaust emissions would be directly attributable to the alternate fuel technology.

The results shown in Figure VI-3, and corresponding Table VI-1, show the effects of alternative fuels on vehicle emissions with the size of the fleet held constant. As shown in Figure VI-3, the total level of emissions for natural gas, methanol and natural gas are greater than the use of diesel technology. These increases are due to CO emissions for methanol and gasoline, and NOx emissions for natural gas. It should be noted that although CO emissions from the methanol engine are greater than its diesel counterpart, the methanol engine does meet emissions standards. As indicated in Table VI-1, all four alternative fuels can reduce particulate emissions.



Source: Appendix D

Figure VI-3. Incremental Exhaust Emissions-Vancouver Scenario 3:No Weight Penalty

Table VI-1. Incremental Exhaust Emissions for Scenario 3

Incremental Emissions (tonnes)	Particulate Trap	Methanol	Natural Gas	Gasoline
HC	0	77	1,388	(33)
CO	0	8,721	321	13,117
NOx	0	(3,948)	17,829	(3,373)
PM	(265)	(265)	(315)	(310)
Total	(265)	4,584	19,222	9,401

Scenarios 4, 5, and 6 - Methanol and Natural Gas Research Engines

From scenarios 1, 2, an 3, it is evident that the current technology for methanol and natural gas do not address all the emissions concerns. Scenarios 4, 5 and 6 were therefore introduced to examine the latest improvements in engine technology under development by the manufacturers. These improved technologies are represented by the pre-production DDC 6V92TA methanol engine and the Cummins L-10 natural gas engine. The results are shown in Figures VI-4, VI-5, and VI-6. Analysis of the results shows that, while significant improvements where achieved by both fuels, only the pre-production methanol engine achieves a net reduction in tailpipe emissions under all scenarios. In the best case scenario (Figure VI-6), methanol produces a total decrease of 4,076 tonnes. Total natural gas emissions are essentially the same as the diesel bus case. Gasoline increase total emissions due to high carbon monoxide levels. As expected, all four fuels reduce particulate matter.

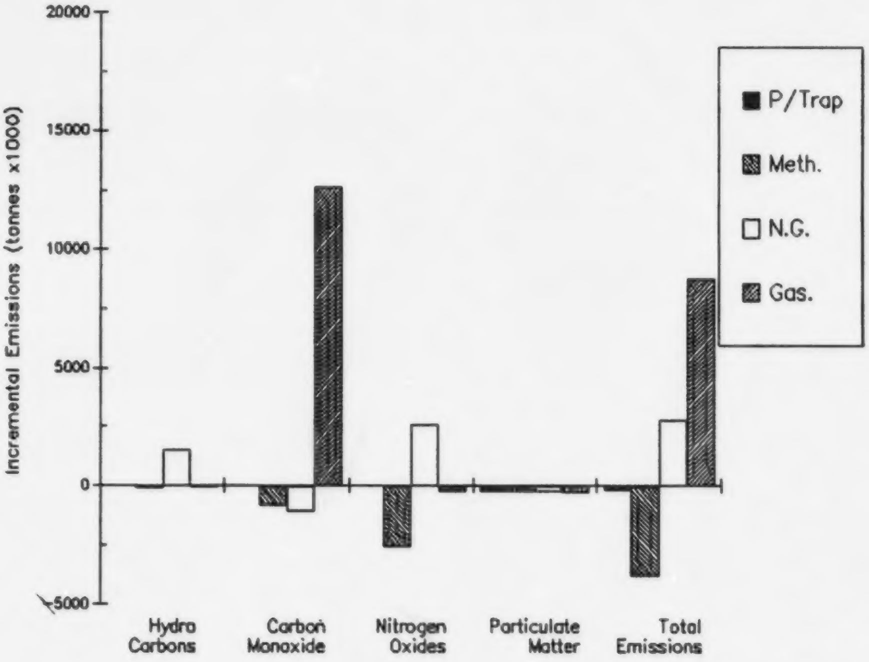


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Figure VI-4. **Incremental Exhaust Emissions - Vancouver Scenario 4: Research Engines/Weight Constraints**

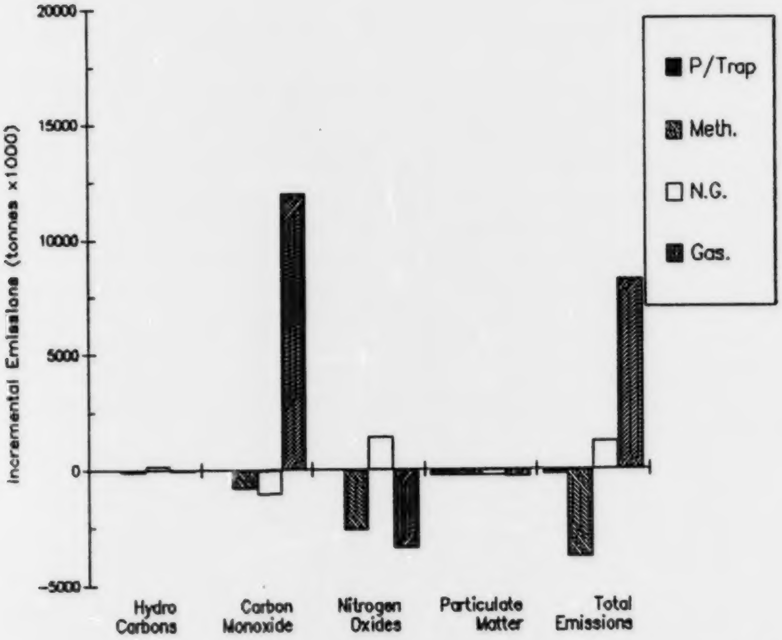

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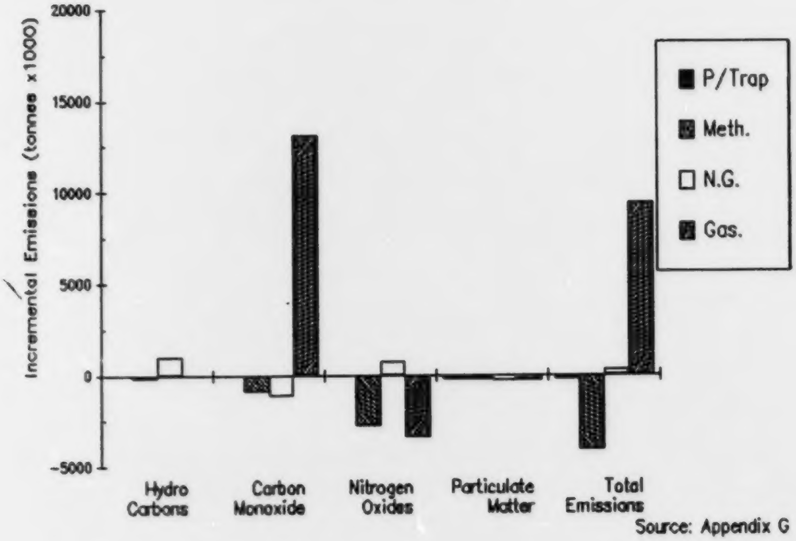
Figure VI-5. Incremental Exhaust Emissions - Vancouver Scenario 5: Research Engines/Half Fuel Load



Source: Appendix G

Figure VI-6. Incremental Exhaust Emissions - Vancouver Scenario 6: Research Engines/Zero Weight Penalty

Reduced Emissions With 1988 Standards

On December 1, 1988, new exhaust emissions standards were promulgated for heavy duty diesel engines. The effect of these new standards was to force the transit bus operators to switch from the familiar DDC 6V71N engine to the cleaner DDC 6V92TA. The 92TA engine, although larger and more powerful, is more fuel efficient and does meet more stringent exhaust emission standards.

The Forecast Model examined the emissions consequences of switching from the 6V71N to the 6V92TA engine and found that the accumulated twenty year emissions from the Vancouver fleet, for example, would be reduced from 25 805 tonnes to 17 759 tonnes. This represents a reduction of 8046 tonnes, or 31.2% during the transitional period. Methanol is projected to reduce emissions by about 4000 additional tonnes over the same time period using the best scenario.

Table VI-2 illustrates the projected emission reductions by emission consistent for all five fleets, during the transitional period during which the 6V92TA engine is introduced. Total emissions reductions are projected at 51,960 tonnes.

Table VI-2. Projected Emissions Reductions With the 6V92TA Engine

Emission	Tonnes Reduction
HC	(2640)
CO	31,280
NOx	22,520
PM	800
Total	51,980

Note: ( ) indicates an increase:

National Exhaust Emissions Levels With Alternative Fuels

To examine the impact of the alternative fuels on a national scale, the Forecast Model was run for each of the remaining fleets (Edmonton, Hamilton, Toronto and Montreal) based on the assumptions in scenario 6. Table VI-3 presents the incremental emissions for each city and the totals for the five cities.

What is striking about Table VI-3 is the poor correlation between fleet size and incremental exhaust emissions. For example, Vancouver's fleet size is 596 whereas Edmonton's is 669; a difference of 12%. Yet Vancouver's emissions for particulate traps is 265 tonnes reduction compared with Edmonton's 119 tonnes reduction. (A difference of 55%). Similarly the correlation between fleet size and emissions is also not linear for the other cities. The major factors that influence the emissions levels are fleet mileage, age of fleet, length of transition phase and duty cycle. Thus, even though Table VI-3 represents 55% of all urban buses in Canada, extrapolation to predict emissions for the balance of Canada can at best only be a rough estimation.

Table VI-3. National Incremental Emissions With Alternative Fuels

		Vancouver	Toronto	Edmonton	Hamilton	Montreal	TOTAL
Fleet Size		596	1525	669	314	2146	5250
Particulate Trap:	HC	0	0	0	0	0	
	CO	0	0	0	0	0	
	NOx	0	0	0	0	0	
	PM	(265)	(727)	(119)	(29)	(446)	(1586)
	Total	(265)	(727)	(119)	(29)	(446)	(1586)
Methanol:	HC	(166)	(448)	(73)	(17)	(275)	(979)
	CO	(868)	(2364)	(397)	(93)	(1456)	(5178)
	NOx	(2776)	(7527)	(1259)	(299)	(4627)	(16488)
	PM	(265)	(714)	(119)	(27)	(446)	(1573)
	Total	(4075)	(11053)	(1848)	(438)	(6804)	(24218)
Natural Gas:	HC	979	2658	445	106	1634	5822
	CO	(1134)	(3078)	(516)	(122)	(1894)	(6744)
	NOx	730	1987	333	79	1218	4347
	PM	(288)	(783)	(131)	(31)	(483)	(1716)
	Total	287	784	131	32	475	1709
Gasoline:	HC	(33)	(98)	(14)	(3)	(52)	(200)
	CO	13117	35535	5956	1412	21848	77868
	NOx	(3373)	(9136)	(1530)	(363)	(5622)	(20024)
	PM	(310)	(853)	(142)	(34)	(520)	(1859)
	Total	9401	25448	4270	1012	15654	55785

C. ECONOMIC AND FINANCIAL COSTS

Economic Costs

In addition to investigating changes to emissions, the Forecast Model examined the incremental economic and financial costs of implementing each alternative fuel. Table VI-4 presents the NPV economic costs for each alterative fuel. The economic costs do not include any taxes imposed on the diesel and alternative fuels. Table VI-4 presents the costs for two different assumptions. The first set of costs assumes vehicle carrying capacity is reduced and additional buses are required to make up the operational shortfall. The second set of costs assume that there are no weight constraints.

As shown in Table VI-4, if carrying capacity is reduced, fleet costs are high due to increased vehicle infrastructure, operations and maintenance costs. This is particularly true for methanol and natural gas due to the extra weight of the fuel and fuel storage. For gasoline, fewer buses are required because of the lighter weight gasoline power train.

When the weight constraint is removed, costs are reduced significantly for methanol and natural gas but increase for gasoline. As shown for scenario 3 and 6 (no weight constraints), natural gas is the least expensive alternative due primarily to its relatively inexpensive fuel costs. The inexpensive fuel costs are, however, offset by major capital costs in vehicle and infrastructure. Methanol is significantly more costly than natural gas due to its fuel costs. Gasoline is also more costly due to fuel costs.

Table VI-4. Economic Cost Summary
(Vancouver)

	Particulate Trap	Methanol	Natural Gas	Gasoline
Scenarios 1 and 4 (Reduced Carrying Capacity)				
Buses Purchased	605	649	754	578
Incremental NPV Costs ($000)				
- vehicle	2,285	7,427	24,098	(5,021)
- infrastructure	0	410	10,227	293
- fuel	6,683	28,323	(5,436)	25,505
- operations and maintenance	2,724	22,578	75,369	(5,544)
- salvage value	(291)	(1,018)	(5,074)	0
Total	11,401	57,720	99,184	14,406
Scenarios 3 and 6 (no Weight Constraints)				
Buses Purchased	596	596	596	596
Incremental NVC Costs ($000)				
- vehicle	1,713	1,713	6,168	(2,399)
- infrastructure	0	410	8,862	353
- fuel	6,229	19,566	(12,550)	27,709
- operations and maintenance	497	353	4,406	4,799
- salvage value	(218)	(291)	(2,352)	(106)
Total	8,221	21,752	4,534	30,358

The costs of the methanol alternative was also estimated using methanol prices based on a 10,000 metric ton per day methanol plant built to serve the California market. Although this plant would probably not be on stream until the late 1990's, the impact of the lower fuel price was assessed.

As shown in Table VI-5, the NPV cost of the methanol option is reduced to $6.2 million over the transition period. This compares to $22 million for the higher-priced methanol option.

Table VI-5. Low Cost Methanol Fuel

(No Weight Constraints)

Incremental NPV Costs ($000)	
■ vehicle	1,713
■ infrastructure	410
■ fuel	4,107
■ operations and maintenance	353
■ salvage value	(291)
Total	6,202

Financial Costs

The previous analysis presented the results of the economic cost analysis which excluded any taxes on diesel and alternative fuels. This section describes the financial cost of alternatives that the fleet owners would face. Financial costs include fuel taxes. As can be seen in Table VI-6, taxes on the fuels significantly impact the costs of the alternatives. (Financial costs are presented for scenario 6 - no weight limit.) Natural gas becomes extremely attractive to the transit property with NPV savings of $19 million for the City of Vancouver. This savings is entirely due to the savings of fuel taxes that are applied to diesel fuel. There is virtually no tax on natural gas. This is not the case for particulate traps, methanol and gasoline which are taxed, although the tax per litre of methanol is lower than the tax on diesel or gasoline.

All of the three other alternatives impose a financial burden on the fleet operator. The financial feasibility of methanol is much more attractive if one assumes low-priced methanol produced for the California market. With that assumption, there is a $30 million NPV savings to the operator over the bus replacement period.

Table VI-6. Financial And Economic Cost Comparisons

Vancouver

	Particulate Gas	Methanol	Natural Gas	Gasoline
Economic NPV Costs ($000)	8,221	24,807	4,534	30,358
Financial NPV Costs ($000)	11,440	34,850	(19,241)	66,553

Cost-Effectiveness

This section presents the results of the analysis by combining potential emissions reduction of each alternative with the cost of that alternative. The results presented here are for scenario 6. This scenario includes the most promising emission profiles and the assumption that extra weight due to an alternative fuel does not reduce carrying capacity. As shown previously, costs of the alternative increase rapidly as well as total emissions due to the extra buses required to make up for reduced carrying capacity. As shown in Table VI-7, under the assumptions for scenario 6, methanol is the most cost-effective in tonnes of emissions reduction at $5000 per tonne. The cost per passenger is approximately 1¢ per trip. The cost per tonne for particulate traps is high because only particulate matter is controlled. With natural gas and gasoline there is an increase in total emissions (although the increase with natural gas is very small). Therefore, there is no emission benefits with these two fuels relative to the introduction of the 6V92TA engine.

Table VI-7. Cost-effectiveness of Alternative Fuels
Vancouver

	Particulate Gas	Methanol	Natural Gas	Gasoline
Cost Per Tonne of Emissions Reduced	$31,000	$5,000	Emissions Increase	Emissions Increase
Cost Per Passenger	0.4¢	1.1¢	0.2¢	1.5¢

Notes: 1. All costs based on Economic NPV costs found in scenario 6.

Results are similar for the other four fleets. If methanol were to be implemented for the five fleets, the economic NPV cost would be approximately $200 million. The total cost in 1989 dollars (without a discount factor) would be about $450 million over a period of about 20 years.

VII EMISSIONS PROFILE - FUEL PRODUCTION

A switch to an alternative fuel may reduce some of the regulated exhaust emissions released by transit fleets. However, associated with the increased demand for a specific alternative fuel will be a greater through-put at alternative fuel production facilities. Therefore, when considering the adoption of an alternative fuel, it is necessary to examine the environmental impact of the increased pollutants emitted at the manufacturing and processing plants.

The emissions resulting from the production of diesel, gasoline, natural gas, and methanol are given in the following sections and are reported in grams of a particular emissions (HC, NO_x, CO, Particulates, SO_x, CO_2) per litre of fuel produced for methanol and diesel/gasoline; and grams per cubic metre for natural gas.

A. NATURAL GAS

Natural gas is commonly referred to as being sour or sweet. In sour gas, the hydrogen sulfide (H_2S) content is at a level that is not acceptable for combustion. The typical composition of sweet natural gas is 95% CH_4, 4% N_2, and 1% other alkanes, principally ethane (54). Canada's abundant supply of natural gas is extracted using high-pressure wells. Unfortunately, this wellhead natural gas contains many impurities which must be removed. The level and type of impurities depend on the location of the well.

The sulphur content of natural gas found in Alberta varies from as low as 1 ppm to 60% sulphur. In north eastern Alberta the sulphur content of sour natural gas is very low and is commonly reported as less than 1 ppm. In southern Alberta the sulphur content of sour natural gas is approximately 20%. Sour natural gas extracted from central Alberta has the highest sulphur content with a natural gas extraction site recently discovered having 60% sulphur content (Caroline, Alberta).

Natural gas extraction companies must get their product (natural gas) to the user and do so via pipeline companies. The pipeline companies will not allow natural gas into their pipeline system if the sulphur content of the gas is higher than 4 ppm. Natural gas found in north eastern Alberta (1 ppm sulphur) meet these requirements and thus can be transported to the user immediately after extraction from the ground. Natural gas extracted from all other parts of Alberta have considerable amounts of sulphur which must be removed before entering a pipeline.

At the well, extracted natural gas is passed through field separators to remove hydrocarbon condensate and water. Gas processing plants (see Figure VII-1) are utilized for recovery of other liquefiable constituents commonly found in the natural gas, such as natural gasoline, butane, and propane. To make sour gas sweet, the sulphur must be removed in a gas sweetening plant.

The major emission sources in the natural gas processing industry are hydrogen sulfide wastes from gas sweetening plants. Compressor engines used to transport the gas from the field to the processing plant as well as the compressor engines used in the processing plant are other sources of emissions but are small in comparison to the larger hydrogen sulfide wastes.

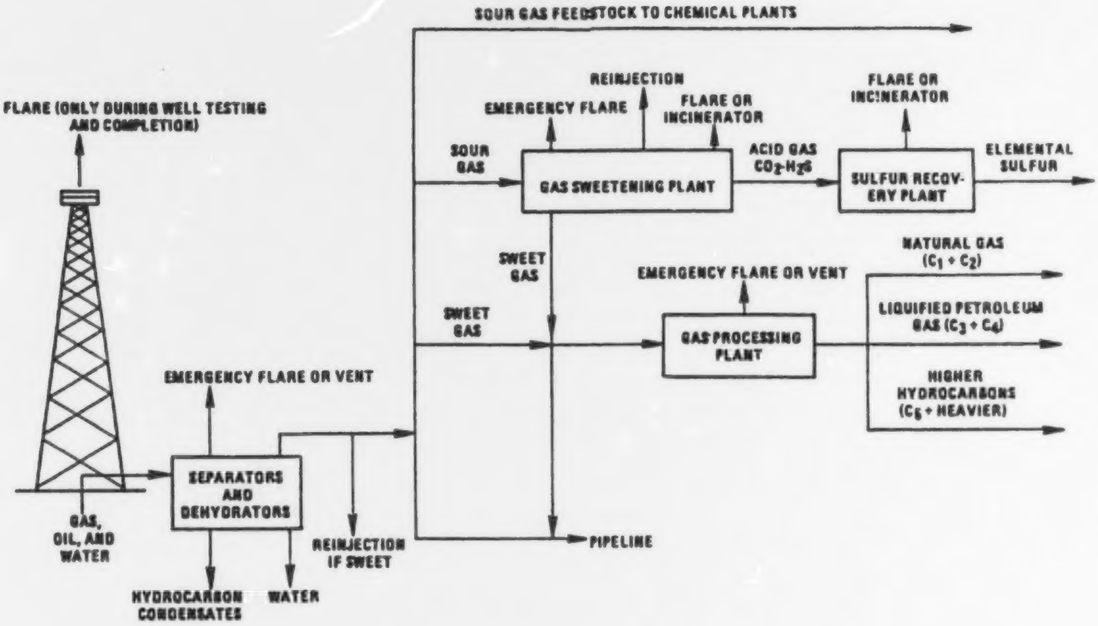

SOUR GAS FEEDSTOCK TO CHEMICAL PLANTS
FLARE (ONLY DURING WELL TESTING AND COMPLETION)
REINJECTION
EMERGENCY FLARE
FLARE OR INCINERATOR
FLARE OR INCINERATOR
SOUR GAS
GAS SWEETENING PLANT
ACID GAS CO_2-H_2S
SULFUR RECOVERY PLANT
ELEMENTAL SULFUR
SWEET GAS
EMERGENCY FLARE OR VENT
NATURAL GAS (C_1 + C_2)
SWEET GAS
GAS PROCESSING PLANT
LIQUIFIED PETROLEUM GAS (C_3 + C_4)
EMERGENCY FLARE OR VENT
HIGHER HYDROCARBONS (C_5 + HEAVIER)
SEPARATORS AND DEHYDRATORS
GAS, OIL, AND WATER
REINJECTION IF SWEET
PIPELINE
HYDROCARBON CONDENSATES
WATER

Figure VII-1. Flow Diagram of Natural Gas Processing

1. Process Description

The most widely used method for gas sweetening is the Amine Process, also commonly referred to as the Girlder Process. This process utilizes amine solutions (solutions derived from ammonia) for absorbing H_2S. This process is summarized in reaction (a), and illustrated in Figure VII-2.

a) $2RNH_2 + H_2S = (RNH_3)_2S$

where: R = mono, di, or tri-ethonal
N = nitrogen
H = hydrogen
S = sulfur

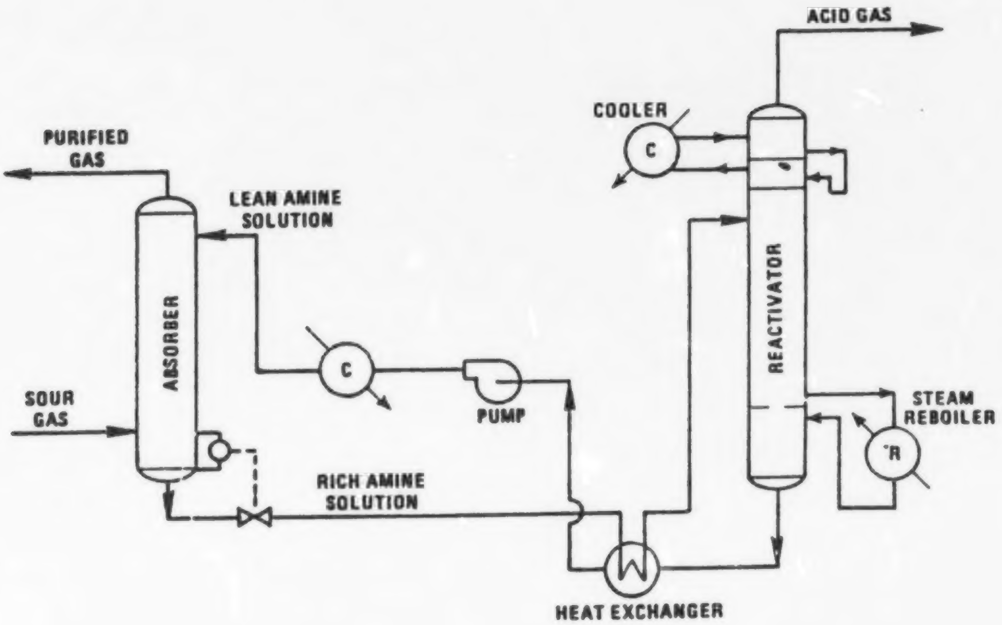


Figure VII-2. Flow Diagram of the Amine Process for Gas Sweetening (54)

Many processes exist to dispose of the hydrogen sulfide removed from the sour natural gas. The gas stream may be either flared in waste gas flares, modern smokeless flares, vented, incinerated, or used for the production of elemental sulphur. The recovery of elemental sulphur from sour natural gas is almost complete with only 0.1% of the sulphur released as airborned emissions. The majority of the sulphur (99.9%) in sour natural gas is removed and transported usually by rail for use as feedstock in the production of products such as fertilizer and battery acid.

2. Emissions

When sweetening is necessary, elevated smokeless flares or tail gas incinerators are utilized to ensure complete combustion of all waste gas constituents, thus resulting in virtually a 100 percent conversion of H_2S to SO_2.[1] Minute quantities of particulates, smoke, and hydrocarbon emissions result from these devices and because gas temperatures rarely exceed 650 degrees Celsius, no significant quantities of nitrogen oxides are formed. Emissions from gas sweetening plants with smokeless fares or incinerators are found in Table VII-1. These emissions do not include emissions released during well testing or emergencies. It was assumed that the sour natural gas feedstock would have a 20% sulphur concentration upon removal from the ground.

Table VII-1. Emission From Sweetening Process
(gram emissions/m^3 gas processed)

Process	Particulates	SO_x	CO	HC	NO_x	CO_2
Amine Produced	Neg.	0.1665	Neg.	Neg	Neg.	NA

a) reference 1

- Neg. = Negligible
  NA = Not Available

Some of the older sweetening plants still in use utilize less efficient gas flares. Because these flares typically burn at temperatures below those necessary for complete combustion, increased HC and particulates emissions will occur along with incomplete conversion of the H_2S stream to SO_2. No data was available to estimate the magnitude of these emissions from waste gas flares.

Engines in the natural gas industry are primarily used for collecting gas from wells, underground storage, and gas processing plant applications (54).

Besides carbon dioxide, the primary pollutant of compressor engines utilized in the natural gas industry is nitrogen dioxide (NOx), which is due to the compressor's operational temperature. NOx readily forms at high temperatures, pressures, and in the excess air environment found in natural gas fired fixed compressor engines. Sulphur dioxide emissions are proportional to the sulphur content of the fuel powering the compressor.

Regulation of compressor emissions have mainly been directed at limiting NOx emissions. NOx reductions of up to 80% can be achieved through the injection of water into the combustion chamber, however the water injection results in reductions in the nominal turbine efficiency.

Emission factors for natural gas fired compressor engines used in field gathering and processing plant applications are reported in Table VII-2. It is assumed the sweetening plant is located close to the gas fields, therefore the sour gas would not be transported great distances. As reported by Sperling, (56) the energy used in gas transmission from the well to the plant as well as plant processing is five percent of the energy withdrawn from the reservoir. Therefore approximately 0.05 m^3 of natural gas is consumed through field gathering and processing equipment for every cubic metre of natural gas processed. The emissions released through combustion of this 0.05 m^3 of natural gas is calculated using the emission factors reported in Table VII-2 and are seen in Table VII-3 in grams of emissions per cubic metre of natural gas produced.

Table VII-2. Emission Factors For Field Gathering and Process Plant Engines

(grams emissions/m^3 gas burnt)

Process	NO[a]	CO	HC[b]	SO_x[d]	Part[c]	CO_2
Gas Turbine Compressor	4.700	1.940	0.280	0.009	NA	N/A

Notes:

- a These factors are for compressor engines operated at rated load.
- b These factors represent total hydrocarbons, nonmetal hydrocarbons are estimated to make up to 5-10 percent of these totals.
- c Not Available,

Table VII-3. Emission From Field Gathering and Process Plant Engines

(gram emissions/m^3 of gas processed)

Process	NO_x	CO	HC	SO_x	Part	CO_2
Field Gathering & Plant Engines	0.235	0.097	0.014	.0005	NA	NA

Emissions from the amine process and compressor engines constitute the majority of emissions released by natural gas processing and the sum of these released emissions are tabulated in Table VII-4.

Table VII-4 Emission From Natural Gas Processing

(grams emissions/m^3 gas processed)

Process	Part.	SO_x[b]	CO	HC	NO_x	[a]CO_2
Amine Process	Neg.	.1665	Neg.	Neg.	Neg.	N/A
Field Collection	N/A	.0005	.0970	0.0144	.235	N/A
Total	N/A	0.1670	0.097	0.0144	0.235	104.1

N/A = not available
neg = negligible
a = taken from reference 3, not available for the two separate processes

B. METHANOL

Various resources can be used as feedstock to produce methanol, some of which include coal, biomass, and natural gas. Natural gas is the most common feedstock used in Canada for the production of methanol. Similar to the compressed natural gas scenario, it is assumed that sour natural gas having a 20% sulphur content (extracted from Alberta) would be used as feedstock. Before the sour natural gas enters the pipeline to be transported to the methanol plant the gas must be sweetened to meet the pipeline sulphur content regulations.

There are four main process steps involved in the production of methanol from natural gas (57). Each of these steps will be discussed briefly.

1. Process Description

The four main process steps involved in the production of methanol are:

a) Synthesis Gas Preparation
b) Compression
c) Synthesis
d) Distillation

A simplified process diagram of the process is shown in Figure VII-3.

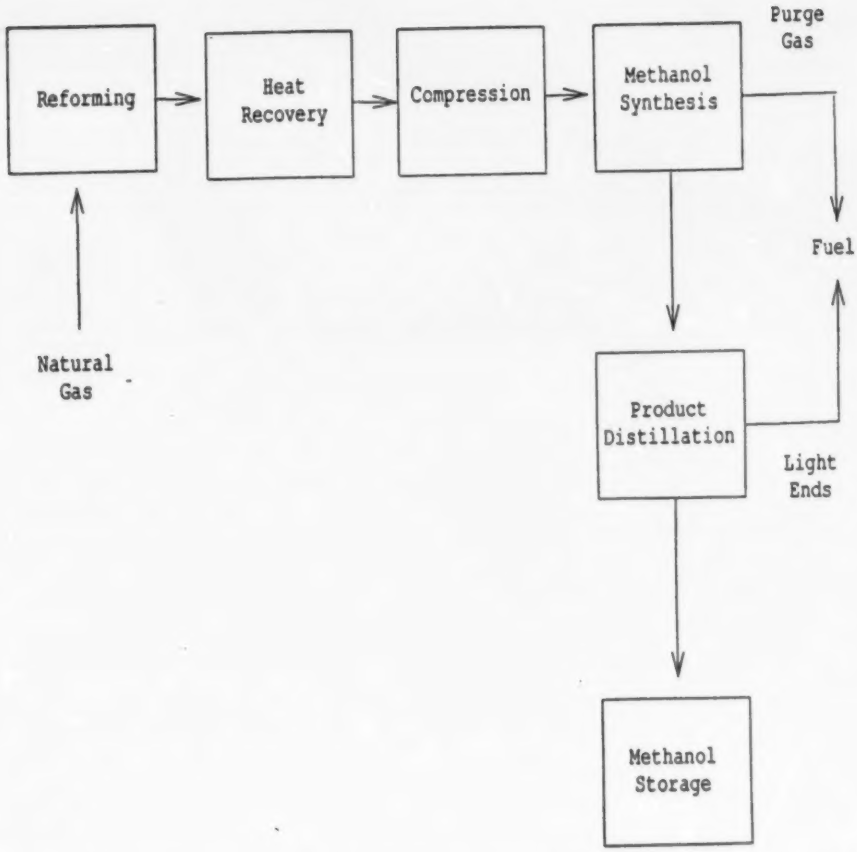
a) Synthesis Gas Preparation

The synthesis gas preparation consists of two basic steps, reforming the sour gas and then recovery of heat used in the reforming process, as depicted in Figure VII-3.

The feedstock for methanol production is sweet natural gas (less than 4 ppm sulphur). The natural gas is preheated and sweetened further, first by converting any organic sulphurs to inorganic ones, and then by absorbing these inorganic sulphurs in zinc oxide catalyst. The gas is then mixed with steam and preheated before being injected into heated catalyst filled tubes of the reformer furnace. Here the gas reforms to hydrogen and carbon dioxide. The reformed gas is then cooled by the heat recovery step as seen in Figure VII-3, and water is condensed out. The majority of airborne emissions from this synthesis gas preparation step are package boiler flue gases, reformer flue gases, and the absorber exhaust.

b) Compression

Dry reformed gas is compressed to the synthesis gas reaction pressure. Unreacted synthesis gas from the methanol converter is recycled back to the synthesis loop.


Reforming
Heat Recovery
Compression
Methanol Synthesis
Purge Gas
Fuel
Natural Gas
Product Distillation
Light Ends
Methanol Storage

SOURCE: DM International, Production of Methanol From a Combination of Wood and Natural Gas Feedstocks, presented at the First International Conference on Fuel Methanol (Houseton, Texas: October 1982) (58).

Figure VII-3. The Simplified Natural Gas To Methanol Process

c) Synthesis

During synthesis, gases from the syntheses gas compressor and circulator pass through the methanol converter where carbon oxides and H_2 react exothermically in the presence of a catalyst to form methanol (CH_3OH) vapour. The converted effluent is cooled, separating the methanol-water mixture (crude methanol) from the unreacted gas. The airborne emissions released from this step are caused by flaring flue gases.

d) Distillation

Crude methanol is then sent to an extraction column where low boiling compounds (light ends) are removed. The methanol-water mixture leaving the extraction column is distilled in a refining column to give 99.9% CH_3OH from the top and 99% H_2O out of the bottom and diluted ethanol along the column. A side stream is drawn off the refining column and sent to a recovery tower where the by-product ethanol is concentrated and removed from the distillation system. Additional methanol is recovered from the top while the ethanol stream leaving the bottom is used as a fuel for the package boiler. Product methanol is drawn from both the refining column and the recovery column. The non-condensible gases, (purge gases) are not usable, so are burnt.

The chemical equations that describe methanol production from natural gas are :

				Synthesis		
CH_4	+	H_2O		CO	+	$3H_2$
Methane		Steam	=	Carbon Monoxide		Hydrogen

CO	+	$2H_2$		CH_3OH
Carbon Monoxide		Hydrogen	=	Methanol

2. Emissions

The emissions released from the production of methanol include feedstock preparation and methanol conversion plant emissions. The emissions released during the sweetening process are similar to those in the natural gas scenario. A slight difference is due to the energy content of 1 litre of methanol compared one cubic metre of natural gas. Approximately 0.622 m^3 of natural gas is equivalent to 1 litre of methanol. Since the process of converting natural gas into methanol is 97% efficient, approximately 0.641 cubic meters of N.G. are required for the production of 1 litre of methanol. In other words the emissions released from sweetening the natural gas needed to produced 1 litre of methanol is approximately 36% less than for the production of 1 cubic metric of natural gas and is shown in Table VII-5.

Table VII-5. Emissions Released From Natural Gas Processing For the Production of Methanol Fuel

Grams of Emissions Per Litre of Methanol Produced					
HC	NOx	CO	Part.	[a]CO_2	SOX
.0092	0.1506	0.0622	N/A	66.7781	0.1070

N/A = not available

a) reference 3

In addition to the emissions listed in Table VII-5, there are also emissions released from the methanol processing plant.

At various steps of producing methanol, airborne emissions including CO, CO2, N2, O2, H2O, NOx, CH3OH, volatiles and other alcohols are released. Table VII-6 summarizes emissions released from the major processes in grams of emissions per metric tonne of methanol produced.

Table VII-6. Continuous Methanol Plant Emissions

		Airborne Emissions (grams/metric tonne of methanol produced) b, d		
		CO2	NOx	CO
1.	Package Boiler Flue Gases	9953	19	10
2.	Reformer Flue Gases	394572	1004	502
3.	Flare Pilot Flue Gas	3764	7	34
4.	Non Condensible - Purge Gas	5244	0	0
5.	Degassifier Exhaust	195	0	0
6.	Condensate Exhaust	1295	0	0
7.	Deaerator Exhaust	31	0	0
8.	Absorber Exhaust	15679	0	0
	Total	430733	1030	860

Source (57)

Note: There are negligible SOx, HC and particulate airborne emissions released.

The continuous airborne emissions, in Table VII-6, are reported on a weight basis. The conversion from the weight basis to a volume basis is attained by considering the density of methanol (0.794 kg/l). The total emissions in Table VII-6 converted from a weight to a volume basis is shown in Table VII-7 in grams of emissions per litre of methanol produced.

Table VII-7. Emissions Released During Methanol Production

Grams of Emissions per Litre of Methanol Produced					
HC	NOx	CO	Part	CO2	SOx
neg.	0.82	0.68	neg.	342	neg

neg. = negligible

The sum of the emissions released through preparing natural gas for conversion to methanol and the emissions released by the conversion process constitute the majority of emissions. The total emissions in grams of emissions per litre of methanol produced are reported in Table VII-8.

Table VII-8. Total Emissions from Methanol Preparation

	Grams of Emissions per Litre of Methanol Produced					
	HC	NOx	CO	Part	CO_2	SOx
N.G. Prep	0.0092	0.1506	0.0622	N/A	^{a}66.7781	0.1070
Methanol Production	neg	0.82	0.68	neg	^{b}342	neg
Total	0.0092	0.9706	0.7422	N/A	408.78	0.1070

N/A = Not available
neg. = Negligible
a) reference 3
b) reference 3 estimate is higher at 644.2 gram CO_2/litre of methanol produces

C. PETROLEUM REFINERY

More than 2500 products including liquified petroleum gas, gasoline, kerosene, aviation fuel, diesel fuel (mid-distillates), fuel oils, lubricating oils, and feedstocks for petroleum refining are produced by the petroleum industry (54). The refinery processes producing these various products compliment each other, so it is not feasible for a refinery to produce, for example, only gasoline or only diesel fuel. Therefore it is not possible to quantify exactly the airborne emissions released by each of the 2500 products of a petroleum refinery.

1. Process Description

A refinery emphasizing the production of gasoline uses extensive cracking and upgrading facilities and has a product yield based upon one barrel of feed as follows (55):

Gasoline	0.625bbl
Middle Distillates (diesel)	0.207bbl
Fuel Oil	0.105bbl
Coke	0.875lbs
Light Ends	9.02lbs

A simplified flow diagram of a typical gasoline refinery is shown in Figure VII-4.

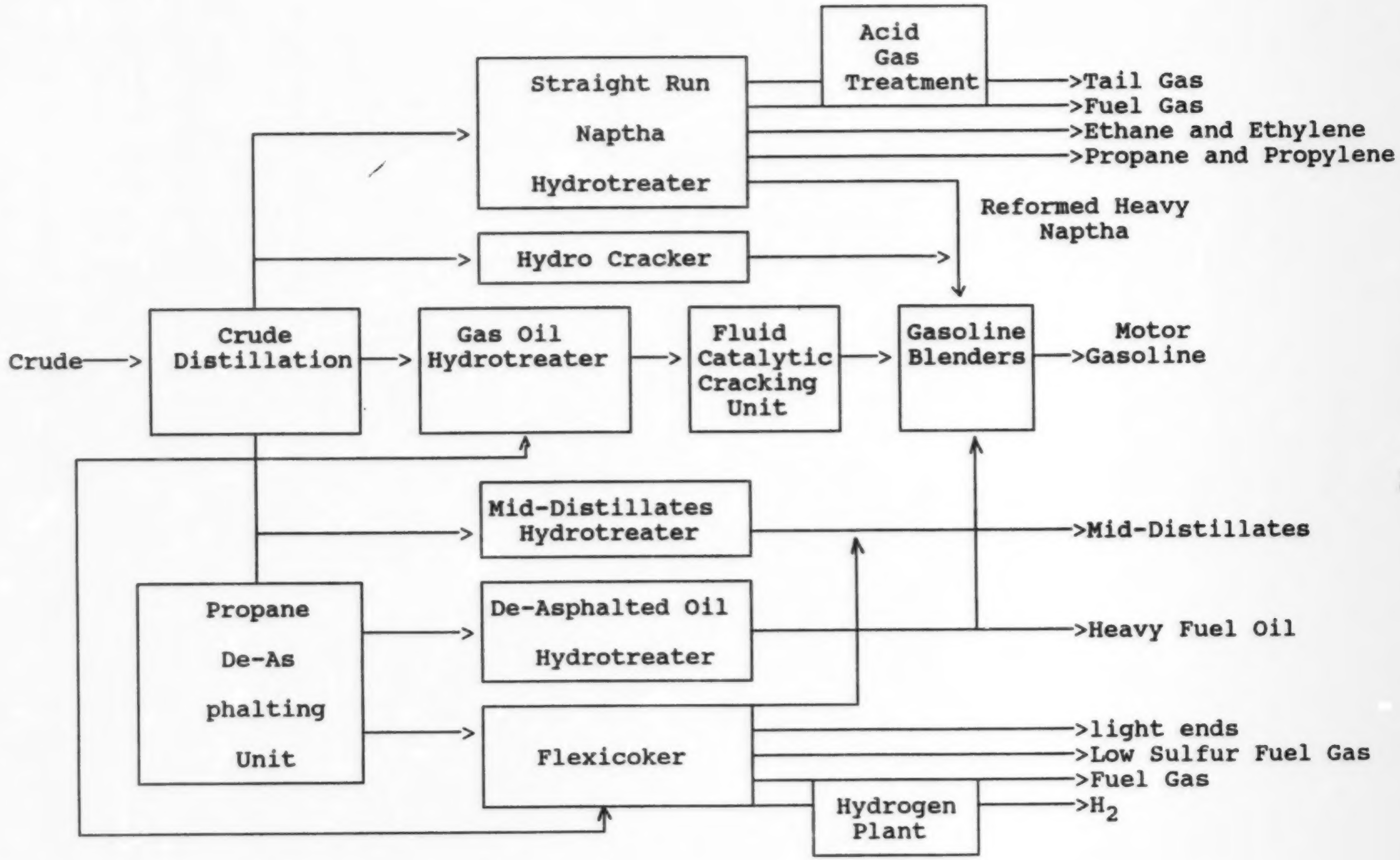

Acid
Gas
Treatment
Straight Run
Naptha
Hydrotreater
>Tail Gas
>Fuel Gas
>Ethane and Ethylene
>Propane and Propylene
Reformed Heavy
Naptha
Hydro Cracker
Crude
Crude
Distillation
Gas Oil
Hydrotreater
Fluid
Catalytic
Cracking
Unit
Gasoline
Blenders
Motor
>Gasoline
Mid-Distillates
Hydrotreater
>Mid-Distillates
Propane
De-As
phalting
Unit
De-Asphalted Oil
Hydrotreater
>Heavy Fuel Oil
Flexicoker
>light ends
>Low Sulfur Fuel Gas
>Fuel Gas
Hydrogen
Plant
>H_2

Figure VII-4. Simplified Gasoline Refinery Processing Sequence

Raw crude is initially separated by crude distillation (Figure VII-4) and distributed to the straight run naphtha hydrotreater, hydro cracker, gas oil hydrotreater, mid-distillates hydrotreater, or the propane de-asphalting unit. The straight run naphtha is hydrotreated (Figure VII-4) and then split into light and heavy naphtha. The end products leaving the straight run naphtha hydrotreater are tail gases, fuel gas, ethane, ethylene, propane, and propylene. The heavy naphtha is reformed and then goes to gasoline blending (Figure VII-4).

The majority of gasoline is produced by the hydro cracker and fluid catalytic cracking unit. Both processes complement each other allowing some flexibility in the production of gasoline. The crude distillate first passes through the gas oil hydrotreater for hydrotreatment to protect the cracking catalyst. After fluid catalytic cracking the products are passed through the gasoline blender where it is mixed with gasoline products from other processes in the refinery like the de-asphalted oil hydrotreater and the straight run naphtha hydrotreater.

Mid-distillate (diesel fuel) is a product from crude distillation and is treated by the mid-distillate hydrotreater for removal of sulphur. Upon exit of the hydrotreater the mid-distillate is put in storage.

Vacuum residuals, a product of crude distillation, are routed to the propane de-asphalting unit for recovery of gas oil, as depicted in Figure VII-4. The gas oil from the de-asphalting oil hydrotreater unit is processed by the de-asphalting oil hydrotreater which produces light ends, naphtha and fuel oil. The light ends continue to the gasoline blending unit and the fuel oil to the heavy fuel oil storage area. The propane de-asphalting unit also produces asphalt. The asphalt goes from the de-asphalting unit to the flexicoker as shown in Figure VII-4. The flexicoker produces distillate, light ends, low sulphur fuel gas, fuel gas and hydrogen.

2. Emissions

The major air pollution sources for particulates, SOx, and NOx within the gasoline refinery module are the process heaters and boilers.

The majority of HC emissions result from general fugitive emissions and from crude and petroleum product storage tanks. Also a primary emitter of SOx is the acid gas treating plant, which removes sulphur from tail gases produced by the straight run naphtha hydrotreaters as seen in Figure VII-4.

Another source of air pollution is the fluidized catalytic cracking unit (FCCU). Uncontrolled, the FCCU would be a major source of particulates, SOx, and carbon monoxide. Controls have however greatly reduced this problem. Air emissions from the specific sources are given in Table VII-9 in pounds of emissions per 200,000 barrels of crude feed occurring on a daily basis.

Table VII-9. Atmospheric Emissions, Gasoline Refinery [55] (lb/day)

Basis : 200,000 bbl/day Crude Feed (input)

	Part.	SOx	CO	HC	NOx	CO2
Crude Distill.	3080	6400	533	533	5330	N/A
Mid-Distill.	45	64	38	65.4	518	"
St run Naphtha	18	26	15	25.7	207	"
Heavy Naphtha	1660	3560	287	288	2870	"
Gas oil hydro.	326	703	57	56	567	"
FCCU	124	176	106	181	1425	"
CO boiler	491	3020	256	160	6370	"
Hydrocracker	131	185	110	1077	1110	"
Heavy Hydro. Crack	1650	3540	285	286	2854	"
Propane Deasphalt.	622	884	48	81	656	"
Hydrogen Plant	1720	345	344	338	6890	"
Miscellaneous	513	3847	191	73709	1193	"
Total	10,380	22,750	2,270	76,800	29,990	NA

Notes:

N/A = not available
Sources: Noyes Data Corporation (56)

As mentioned earlier the product yield from one barrel of crude feed includes 0.625 barrels (bbl) of gasoline and 0.207 bbl of mid-distillates. Because it is not possible to determine the emissions for each separate product (i.e. diesel and gasoline), a worst case assumption in subsequent analysis is chosen in that the full emissions output for both gasoline and diesel will be used.

Table VII-8 reports emissions in pounds per 200,000 barrels of crude feed. 0.625 bbl of gasoline and 0.207 bbl of mid-distillates are produced from every barrel of crude. In this scenario 0.832 bbl of petroleum fuel is produced per bbl of crude feed. So if 200,000 bbl of crude is refined, the volume of petroleum produced is known as well as the emissions from Table VII-9. The conversion from pounds to grams and barrels to litres is performed using the appropriate conversion factors to produce the petroleum refinery emissions in grams of emissions per litre of petroleum (i.e. gasoline or diesel) produced and is shown in Table VII-10.

Table VII-10. Gasoline Refinery Emissions

(in grams airborne emissions per litre of petroleum (gasoline or diesel) produced)

SOx	NOx	CO	HC	Part	[a]CO2
0.098	0.01300	0.0010	0.0333	0.0045	512.4

Notes:

N/A = not available
a) taken from reference Z

D. SUMMARY

Table VII-11 provides a summary of emissions for all the alternative fuels. It should be pointed out that emissions sighted are airborne emissions. Water emissions and solid emissions are not included.

Table VII-11. Process Airborne Emissions

grams emissions/litre of fuel produced

FUEL TYPE	HC	NOx	CO	Part.	CO2	SOx
Methanol	.0092.	0.9706	0.7422	N/A	408.78	0.1070
Natural Gas (a)	0.0144	0.235	0.097	N/A.	104.1	0.167
Gasoline/Diesel	0.0333	0.0130	0.0010	0.0045	512.4	0.098

N/A = not available
neg. = negligible
a) units are in grams emissions/cubic metre

Using the emissions data from Table VII-11, the emissions released for the case of Research Engines-No Weight Limitation (Scenario 6) can be determined. Using the 20-year fuel consumption data from the Forecast Model, the refinery emissions are calculated. Because the Forecast Model looks at the transition from one fuel to another both the quantity of diesel used by the current fleet which is being replaced and the quantity of alternate fuel used by the replacement fleet must be considered. The refinery emission for each fuel must then be calculated and summed. These refinery emissions and the total emissions are shown in Table VII-12. The emissions for CO, HC, NOx, particulates and SOx are shown in tonnes. Total emissions and CO2 emissions are given in kilotonnes.

Table VII-12. Fuel Production Emissions

TREATED EXHAUST - ZERO WEIGHT PENALTY (Scenario 6)

Alternative	Quantity Of Fuel (l x10^6)		CO (tonnes)	HC (t)	NOx (t)	Part. (t)	SOx (t)	CO2 (kilotonnes)
Diesel 6V71	Diesel:	454.2	0.446	15.116	5.902	2.044	44.512	232.732
	Alternative:	0.0						
	Subtotal		0.446	15.116	5.902	2.044	44.512	232.732
L.S. Diesel, P. Trap	Diesel	172.0	0.169	5.724	2.235	0.774	16.856	88.133
	Low S. Diesel	281.3	0.277	9.362	3.655	1.266	27.567	144.138
	Subtotal		0.446	15.086	5.891	2.040	44.423	232.271
Methanol	Diesel	172.0	0.169	5.724	2.235	0.774	16.856	88.133
	Methanol	594.3	441.089	5.468	576.828	N/A	63.590	243
	Subtotal		441.259	5.724	579.063	0.774	80.446	331.07
Natural Gas	Diesel	172.0	0.169	5.724	2.235	0.774	16.856	88.133
	N.G. (m3)	369.6	35.851	5.322	86.856	neg.	62	38.475
	Subtotal		36.020	11.046	89.091	0.774	79	126.608
Gasoline	Diesel	172.0	0.169	5.724	2.235	0.774	16.856	88.133
	Gasoline	423.2	0.416	14.084	5.499	1.904	41.474	216.848
	Subtotal		0.585	19.808	7.735	2.678	58.330	304.980

A review of Table VII-12 indicates that methanol has relatively high levels of regulated emissions particularly CO (441 tonnes) and NOx (579 tonnes). The fuel production emissions partially offset vehicle emission reductions of CO by about 50% and NOx emissions by 25%. Total regulated emissions reductions for methanol are reduced from 4000 tonnes to about 3000 tonnes. Thus there is still a net overall emissions reduction.

For natural gas, regulated emissions from fuel production account for less than 10% of fleet vehicle emissions. Similarly, fuel production emissions for gasoline or diesel are not significant when compared with vehicle emissions.

With respect to CO_2, it would appear that methanol has the highest emissions followed in order by gasoline, diesel and natural gas. When vehicle CO_2 emissions and fuel production CO_2 emissions are added, as in Table VII-13, it would appear that gasoline is the largest source while natural gas produces the least (30% less than gasoline). CO_2 from low sulphur diesel and methanol are comparable at a level of about 17% above natural gas.

Table VII-13. Total Carbon Dioxide Emissions

(000's tonnes)

	Fleet	Fuel Production	Total
Low Sulphur Diesel	1168	232	1400
Methanol	1107	331	1438
Natural Gas	1108	126	1234
Gasoline	1405	304	1709

VIII COMPARISONS WITH EMISSIONS FROM STATIONARY SOURCES

A. INTRODUCTION

This section looks at stationary sources of atmospheric emissions and puts into perspective the role that they play in the overall picture. The emissions discussed are: sulphur dioxide (SO_2), particulate matter (PM), nitrogen oxides (NOx), hydrocarbons (HC), and carbon monoxide (CO). Atmospheric emissions may come from natural sources, as well as anthropogenic; i.e, man-made sources.

The extent of potential damage due to anthropogenic emissions tends to be centered around urban areas where most motor vehicles and stationary sources are located. However, the impact of a specific emission constituent is a function of its residency time in the atmosphere. The longer the residency time of a specific emittant, the greater likelihood exists for broader impact. Particulates present a localized problem. Due to their mass, particulate dispersion is limited. Hydrocarbons, carbon monoxide and nitrogen oxides present more of a regional problem. Carbon dioxide is a global problem because once it is released into the atmosphere, it will only be recycled into oxygen through photosynthesis.

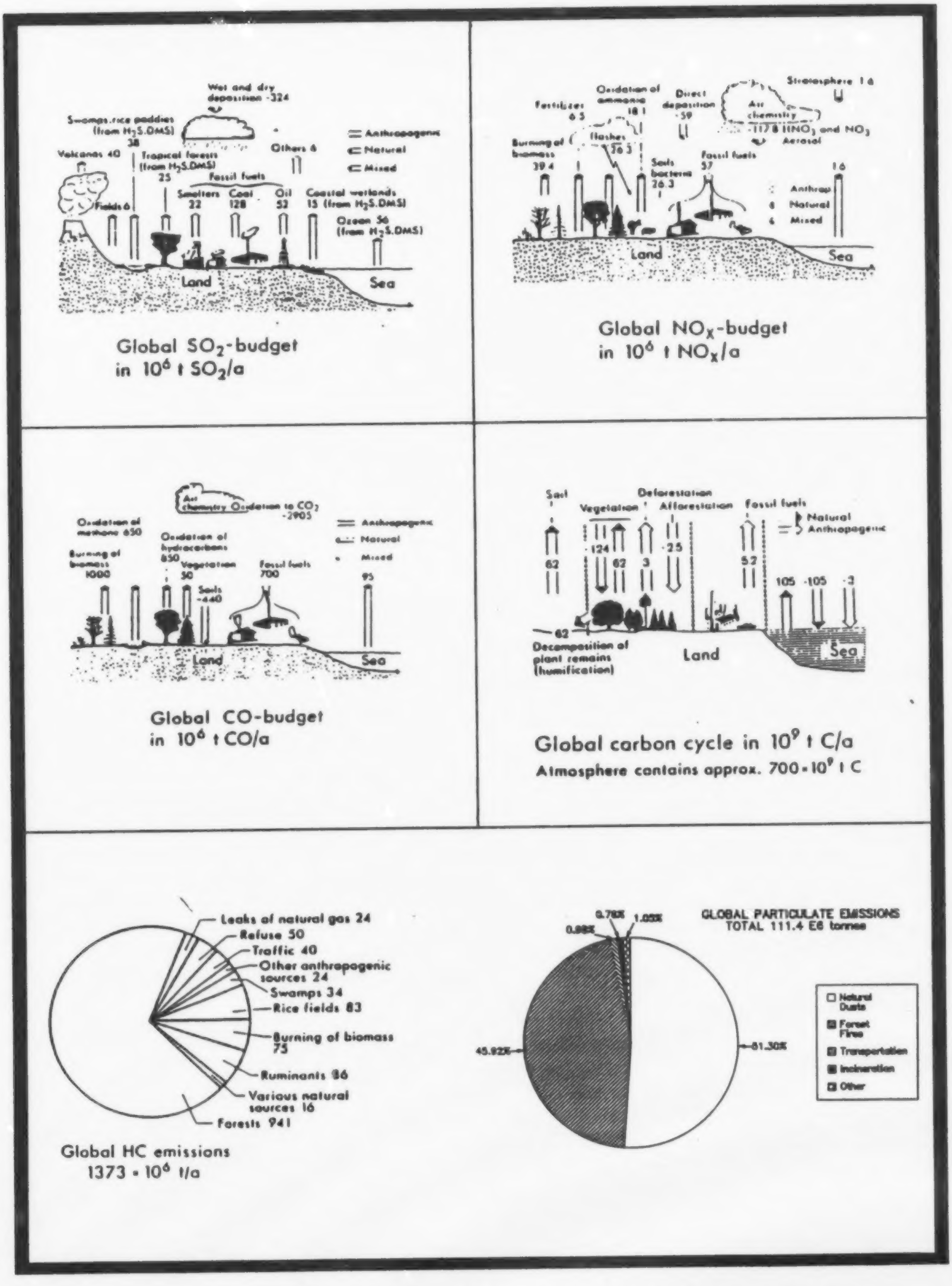
B. GLOBAL PICTURE

Figure VIII-1 outlines the sources of various emissions and gives the total tonnage emitted or absorbed on a global basis. This figure helps to place anthropogenic emissions sources in perspective with natural sources. When examining this figure, it is tempting to discount the role man plays in polluting the environment. For example, transportation (traffic) makes up only 2.9% of global hydrocarbon emissions and anthropogenic sources only supply 8.3% overall. However, the environment is a sensitive and balanced ecosystem: any interference by man is likely to have some deleterious effects.

Emissions from combustion of fossil fuel is the main anthropogenic source of SO_2, NOx, and CO. On a global basis, anthropogenic sources of hydrocarbons represent only 2.9% of all hydrocarbon emissions.

C. TOTAL EMISSIONS IN CANADA

Table VIII-1 outlines the various man-made sources and amounts of emissions in Canada for the year 1985:


Wet and dry deposition -324
Swamps, rice paddies (from H_2S.DMS) 38
Volcanos 40
Tropical forests (from H_2S.DMS) 25
Others 6
Anthropogenic
Natural
Mixed
Fossil fuels
Fields 6
Smelters 22
Coal 128
Oil 52
Coastal wetlands 15 (from H_2S.DMS)
Ozean 56 (from H_2S.DMS)
Land
Sea
Oxidation of ammonia 18.1
Direct deposition -59
Stratosphere 1.6
Fertilizer 6.5
Air chemistry
-117.8 HNO_3 and NO_3 Aerosol
Burning of biomass 39.4
Flashes 26.3
Soils bacteria 26.3
Fossil fuels 57
1.6
Anthrop
Natural
Mixed
Land
Sea
Air chemistry Oxidation to CO_2 -2905
Oxidation of methane 650
Oxidation of hydrocarbons 650
Burning of biomass 1000
Vegetation 50
Soils -440
Fossil fuels 700
95
Anthropogenic
Natural
Mixed
Land
Sea
Soil
Deforestation
Vegetation
Afforestation
Fossil fuels
Natural
Anthropogenic
-124
62
62
3
-2.5
5.2
105
-105
-3
62
Decomposition of plant remains (humification)
Land
Sea
Leaks of natural gas 24
Refuse 50
Traffic 40
Other anthropogenic sources 24
Swamps 34
Rice fields 83
Burning of biomass 75
Ruminants 86
Various natural sources 16
Forests 941
0.78%
1.05%
0.98%
45.92%
51.30%
Natural Dusts
Forest Fires
Transportation
Incineration
Other

Global SO_2-budget in 10^6 t SO_2/a

Global NO_X-budget in 10^6 t NO_X/a

Global CO-budget in 10^6 t CO/a

Global carbon cycle in 10^9 t C/a
Atmosphere contains approx. $700 \cdot 10^9$ t C

Global HC emissions
$1373 \cdot 10^6$ t/a

GLOBAL PARTICULATE EMISSIONS
TOTAL 111.4 E6 tonnes

Figure VIII-1. Global Sources of Atmospheric Emissions ref (51,52)

Table VIII-1. Anthropogenic Sources of Atmospheric Emissions in Canada (38)

(kilotonnes)

	Non-Methane HC		CO		CO_2		NOx		PM	
Mobile Sources:										
Light Duty Vehicles	668.3	37.2%	5449.9	50.6%	71061	16.3%	520.6	26.6%	NE	
Heavy Duty Vehicles	63.6	3.5%	435.5	4.0%	27075	6.2%	285.7	14.6%	23	1.0%
Off Road	138.3	7.7%	1278.1	11.9%	38691	8.0%	446.5	22.8%	28.6	1.3%
	870.2	48.4%	7163.5	66.4%	136827	31.4%	1252.8	63.9%	51.6	2.3%
Point Sources	164	9.1%	3616.9	33.6%	233399	53.6%	593.3	30.3%		
Fuel	164	9.1%	NE		NE		NE		NE	
Industrial Processes	203.1	11.3%	NE		29656	6.8%	88.9	4.5%	NE	
Other	396.6	22.1%	NE		35299	8.1%	24.3	1.2%	NE	
	1797.9		10780.4		435181		1959.3		2200	

Notes: FUEL comprises production, distribution and marketing
POINT SOURCES include residential, commercial, industrial, wood burning and power generation
INDUSTRIAL comprises gas plants, coal production, petrochemical, plastics & kraft pulping
OTHER includes surface coatings, dry cleaning, solvents, etc ...
NE - not estimated
CO_2 estimate is for 1987
Total particulate matter comprises all sources

Table VIII-1 shows that the transportation sector is the primary source of NOx, CO, and HC emissions. Stationary fuel combustion also produces large amounts of NOx and CO2.

The graphs in Figure VIII-2 show projected emissions trends in Canada beginning in 1985. Emissions are expected to initially decrease as newer vehicles subject to more stringent emission regulations enter the market. However, as vehicle fleet size increases along with a corresponding increase in industrial activity, emissions are expected to increase above current levels.

D. SULPHUR DIOXIDE (SO_2):

Sulphur dioxide is a heavy pungent gas that will combine with water to form sulfuric acid. Sulphur dioxide and nitrogen oxides are a primary source of acidic precipitation (acid rain). The primary anthropogenic sources of SO_2 are fossil fuels.

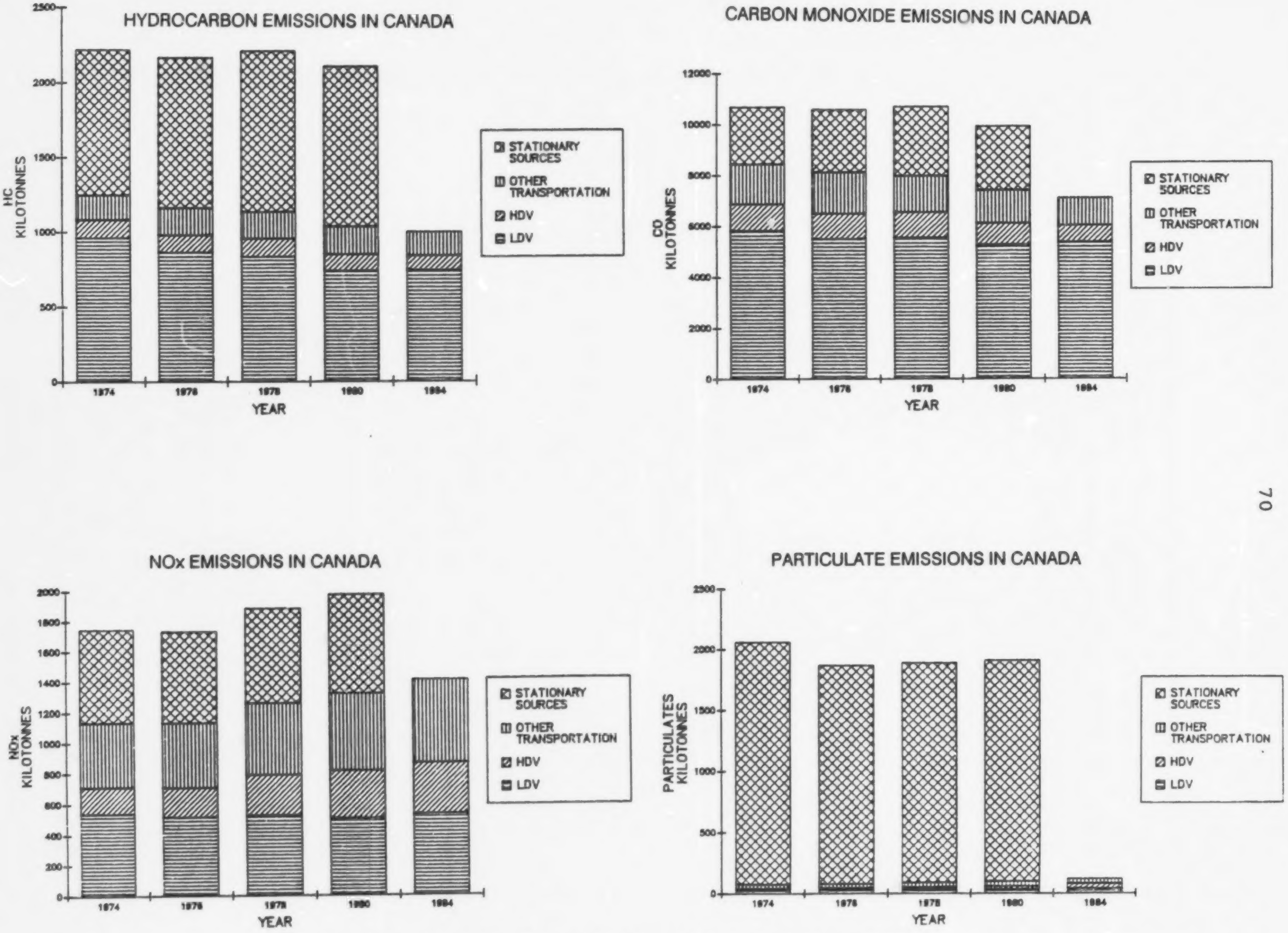


Figure VIII-2. Canadian Trends in Atmospheric Emissions (39)

(Note: stationary source data not available for 1984)

The primary anthropogenic source of SO_2 in Canada are the copper-nickel mining industry and coal-fired thermal power plants. Only in Alberta is the situation somewhat different. The petroleum industry accounts for 81.5% of anthropogenic SO_2 emissions while electrical utilities contribute only 16.6%. Table VIII-2 summarizes the primary sources of Canadian SO_2 emissions. SO_2 emissions from gasoline and diesel sources are negligible compared to stationary sources.

Table VIII-2. Canadian Sources of SO_2 (37)

Sources	SO_2 tons/yr.
INCO Ltd., Copper Cliff, Ontario	866,000
Noranda Mines Ltd., Noranda Quebec	538,000
INCO Ltd., Thompson, Manitoba	359,000
Hudson Bay Mining and Smelting Co., Flin Flon, Manitoba	212,000
Ontario Hydro, Lambton Station, Courtwright, Ontario	160,000
Ontario Hydro, Nanticoke Station, Walpole Township, Ontario	155,000
Algoma Steel Corporation Ltd., Wawa, Ontario	141,000
Falconbridge Nickel Mines Ltd., Falconbridge, Ontario	122,000
Suncor Inc. (Oil Sands Division), Fort McMurray, Alberta	93,000
Ontario Hydro, Lakeview Station, Mississauga *Ontario	91,000

A federal/provincial task force was formed to study the expanded use of low sulphur western Canadian coal in Ontario. Due to its cost advantage, high sulphur coal from the U.S. is currently used. The focus of the task force was on Ontario Hydro. The task force looked at several options: (1) sole use of Canadian coal; (2) sole use of U.S. coal and scrubbers; and (3) a combination of both coals and some scrubbers. The task force found that option (1) would cost about twice as much as option (2) but create new jobs for Canadians and therefore was chosen as the preferred option.

According to the task force, the use of scrubbers would cost an overall \$654 million (1985 value) for emissions reductions from 1985 to the year 2000. This technology would remove 1.62 million tonnes of SO_2 from the source. This works out to approximately \$400/tonne.

If the Western low-sulphur coal is used, the costs are \$1,280 million, for the removal of 1.86 million tonnes. This works out to \$688/tonne for SO_2 removed.

E. PARTICULATES:

The removal of coarse and fine particles from an airstream is referred to as dust collection or particulate control. The 1974 U.S. EPA Standards set the primary level of total suspended particulates at 75 micrograms/cubic meter. The secondary level is 60. Readings taken at background sites show around 35 micrograms/cubic metre. National monitoring sites in the U.S. are closer to the 75 maximum. However, even dust from unpaved roads in non-industrial sectors can lead to a particulate density of 75 micrograms/cubic metre.

There are different sizes and sources of particulates. Suspended atmospheric particulates fall into general types based on their size. Large diameter particulates (over 5 microns) constitute the major mass fraction of most particulate sources. Larger size particulates pose more of an environmental hazard; i.e., unsightly smoke plumes, reduced visibility and soiling. Smaller size particulates are of more concern to human health. These particulates can be easily inhaled and deposited in the lungs. Furthermore, because of their smaller size and hence lower mass, they are more easily transported (dispersed). Figure VIII-3 outlines Canadian sources of anthropogenic particulate emissions.

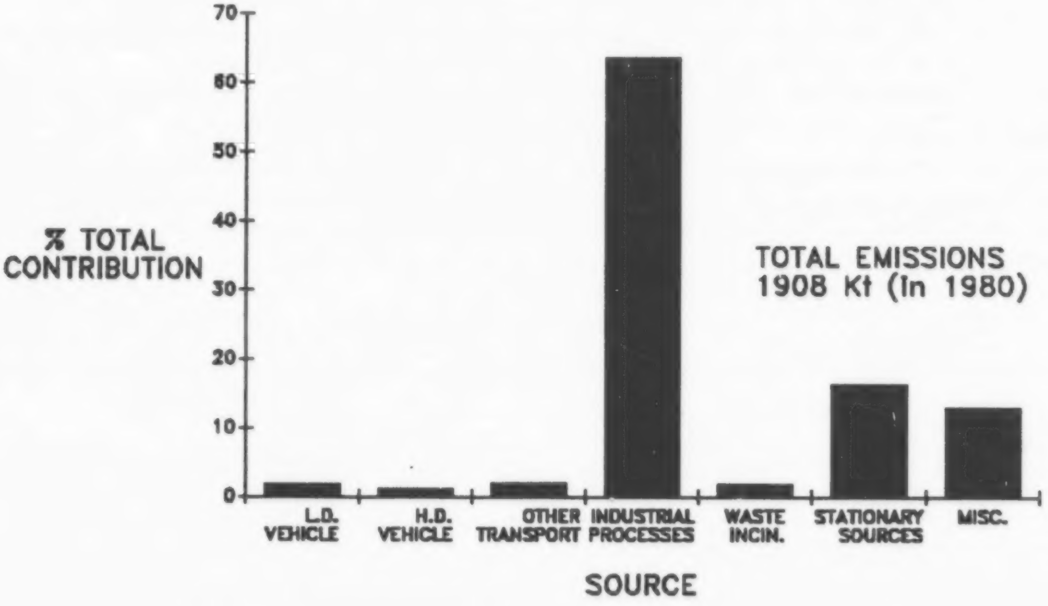


Figure VIII-3. Canadian Anthropogenic Particulate Emissions (39)

F. NITROGEN OXIDES (NOx):

Nitrogen oxides like sulphur dioxide, is a precursor to acidic depositation. Nitrogen oxides are emitted from both natural and anthropogenic sources. On a global scale, the natural sources such as biological decay, lightning, and forest fires represent the primary source of NOx. However, in urban areas the ratio is reversed and the largest sources are anthropogenic.

With respect to anthropogenic sources, the greatest amount of NOx in Canada is from fuel combustion, with the largest contribution being mobile sources. Thermal power plants are the greatest stationary source of NOx in Canada. In the near future, stationary sources will displace mobile sources as the prime source of all anthropogenic NOx. More stringent mobile source exhaust emissions are expected to result in a drop in NOx emissions from these sources.

Approximately 600 kilotonnes of NOx were emitted in Ontario from anthropogenic sources each year from 1980 to 1983. Measurements of NO_2 were taken and 60% was calculated to come from mobile sources, 14% from industrial sites and 20% from thermal power plants (35). In Alberta, the petroleum sector is the primary NOx contributor (38%) whereas electrical utilities contribute 22.4%.

Various control technologies are now available to deal with NOx control from stationary sources. These technologies include combustion modification, fuel modification (including fuel substitution) and flue gas treatment.

It is estimated that low NOx burners which are currently available for the utilities sector can provide one of the least expensive methods of pollution abatement for NOx. According to the Western Canadian Low-Sulphur Coal Task Force, retrofitting with low NOx burners was estimated to cost between $120 to $450/tonne in 1980 dollars. According to estimates by Environment Canada, retrofitting power plants and industrial boilers with low NOx burners would cost between $200 to $500 per tonne. More advanced technology such as selective catalytic reduction would cost between $1000 to $8000 per tonne depending on a new installation or retrofit (36).

G. VOLATILE ORGANIC COMPOUNDS (VOC)

Manmade volatile organic compounds comprise a relative small fraction of total VOC's. Figure VIII-4 breaks down VOC emissions in Ontario for 1980. Anthropogenic sources account for only 2.3% (665,000 tonnes/year).

Figure VIII-5 presents a breakdown of anthropogenic VOC emissions in Ontario by source. Most of these emissions are non-methane. The transportation sector is the single largest source at 257,000 tonnes/year while stationary sources, designated fuel combustion, account for 120,000 tonnes/year. Industrial sources include refineries, the chemical industry and surface coatings.

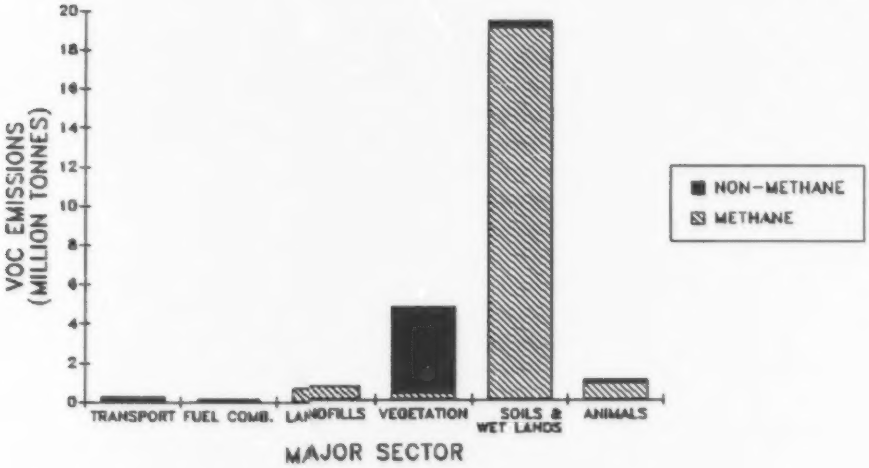


Figure VIII-4. 1980 Ontario VOC Emissions (35)

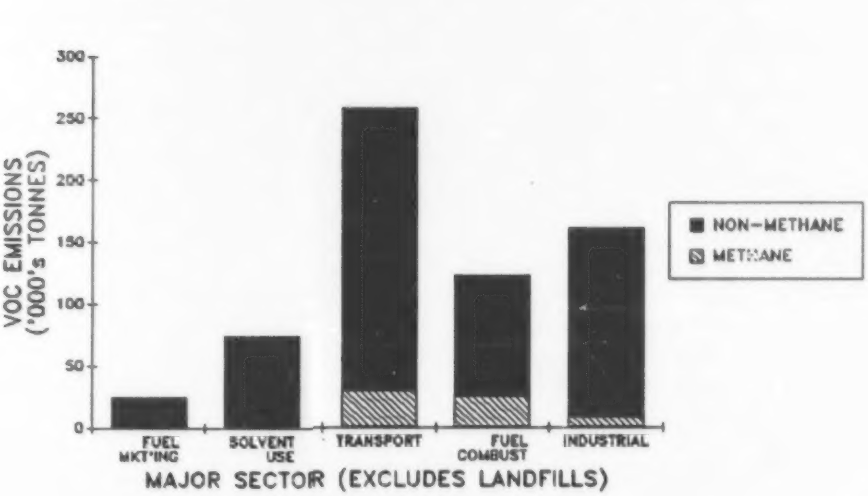


Figure VIII-5. 1980 Ontario Anthropogenic VOC Emissions (35)

The current emphasis on VOC emissions control has been centered around the transportation sector. There are no costs to report on at this time for stationary controls.

H. SUMMARY

Table VIII-3 summarizes the estimated costs of stationary emissions reductions. Based on our literature research, cost estimates were available only for SO_2 and NOx. The cost estimates appear to be substantially less than the methanol fuel alternative for transit coaches.

Table VIII-3. Summary of Stationary Emissions Abatement Costs

	SO_2	NOx
Cost/Tonne	$400-700	$200-500 (low NOx burner) $1000-8000 (advanced technology)

IX SUMMARY AND CONCLUSIONS

This study has conducted an in-depth analysis of the incremental costs and environmental benefits associated with implementing alternative fuels in major Canadian transit fleets. The study has specifically looked at the cost-effectiveness of reductions in regulated emissions in fleet operations. The effect of alternative fuels on CO_2 emissions was also assessed.

The study found that the greatest improvements in emission reductions will be made by fleets switching to newer technology diesel engines as required to meet 1988 emissions standards. The potential reductions are 8000 tonnes at about $150/tonne in Vancouver. This reduction compared with 4000 tonnes reduction at about $5000/tonne for the most optimistic methanol scenario. The study also found that the projected costs of emissions controls for stationary sources may be lower than the use of alternative fuels on a cost per tonne basis.

With respect to the analysis of the alternative fuels, the study found that cost-effectiveness is highly dependent on assumptions about passenger loading due to weight considerations and the projected emission profiles of specific engine-fuel types. Figure IX-1 summarizes the cost-effectiveness of the four alternative fuels considered for three different sets of assumptions to show the effects of weight constraints and emissions profiles. (For the purpose of this chapter, we have labelled these scenarios A, B, and C). As shown in Figures IX-1, reduced passenger carrying capacity due to increased vehicle curb weight is an important factor in natural gas and to a lesser extent for methanol. As shown under scenario A, which assumes capacity is reduced by the additional weight of the alternative fuel, the costs of natural gas and methanol are very high. In each case, extra buses are required to make-up the reduced carrying capacity of individual buses. These extra buses also contribute to increased emissions.

Scenarios B and C assume no weight constraints on carrying capacity. Scenario B uses emission profiles of demonstration or commercially available engines for which there is both emissions and operational field data available. Scenario C uses improved emissions profiles for natural gas and methanol based on "research" engines under current development but for which field data is not yet published. Conclusions are discussed separately for each alternative fuel.

Particulate traps

As shown in Figure IX-1, the cost per tonne is prohibitively high because of the assumption that only particulate matter would be reduced. Other reasons include the increased price of low-sulphur fuel, increased fuel consumption and the cost of the particulate trap. Long-term durability and reliability of a trap system still have to be demonstrated.

The use of catalysts in conjunction with particulate traps was not assessed in the study. Some research is taking place in this area but there is little published data. If the proper technology could be developed at a reasonable cost ($5,000 - $8,000 per vehicle), a particulate trap - catalyst system could be a reasonable alternative.

ALTERNATIVE FUEL	SCENARIO		
	A Weight Constraints: Demonstration Engines	B No Weight Constraints: Demonstration Engines	C No Weight Constraints: Research Engine
Particulate Trap	- very high costs per tonne of emissions ($57,000) - particulate reductions only	- high costs per tonne of emissions ($31,000) - particulate emissions only	- same as previous scenario
Methanol	- very high costs ($57 M) - 53 additional buses - increased emissions due to CO	- high costs ($21 M) - increased emissions due to CO	- high costs ($21 M) - reduced emissions at $5000/tonne
Natural Gas	- very high costs ($99 M) - 158 additional buses - increased emissions due to NOx	- lowest economic cost option ($4 M) - increased emissions due to NOx	- lowest economic cost option ($4 M) - no overall emission reductions
Gasoline	- relatively low cost ($14 M) but increased emissions	- total cost of $30 M with increased emissions	- same as previous scenario

Figure IX-1. Summary Fleet Cost-Effectiveness
(Vancouver)

Methanol

Under scenario B, using emissions data from field demonstration engines, total emissions increase due to more CO emissions relative to diesel engines. However, the CO emissions for the methanol engines are within regulated emissions standards. It should be noted that the study treated each regulated emission equally and did not try to assess the relative merits of reducing one emittant in relation to another. Improved engine emissions, as shown in Scenario C, provide net reductions in fleet emissions in the order of 4000 tonnes during the period under consideration. The estimated cost is \$5000/tonne. The costs of the methanol option are relatively high due to the price of the fuel. Fuel costs could drop by 40-50% if a large 10,000 metric tonne per day plant were built to serve the California market. However, the earliest time frame for this scenario would be around the year 2000. Methanol would then be more attractive as an alternative fuel at a cost of about \$1500 per tonne of reduced emissions.

Natural Gas

Natural gas is the most attractive fuel from a cost point of view if weight concerns are not an issue for a fleet or if weight restrictions could be resolved through changes in bus design, natural gas storage or fleet operations. Natural gas is very attractive to a fleet owner if fuel taxes are considered in the costs. A city such as Vancouver could realize a savings of \$19 million from a conversion to natural gas. This saving is primarily due to savings in fuel taxes. Savings in other cities depends on fleet size and mileage.

The natural gas alternative using demonstration engines has a problem with high NOx emissions that exceed regulated standards. This problem is greatly reduced with the latest engines being developed for field use. It does appear that even more advanced engine design will be needed to provide net emissions reductions relative to diesel fuel.

Gasoline

As anticipated, the conversion to gasoline is both costly and results in increased emissions due primarily to CO. This alternative is not being actively pursued by industry. Instead, production and availability of heavy duty gasoline engines is decreasing as demand decreases.

Fuel Production and Carbon Dioxide Emissions

The study also examined CO_2 emissions and fuel production emissions. The study found that emissions during methanol production partially offset CO and NOx gains during fleet operation by 50% and 25%. For natural gas, gasoline and diesel, fuel production emissions were less than 10% of fleet emissions.

With respect to CO_2 from vehicle operation and fuel production, gasoline is the largest source while natural gas produces the least (about 30% less than gasoline). CO_2 from low sulphur diesel and methanol are comparable at a level of about 17% above natural gas.

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Appendix A

Toronto Star Article On Roadway Damaged Caused By Overloaded Buses

TORONTO STAR MAY 10/89

Overloaded TTC buses major cause of Metro road damage, study finds

By Peter Howell Toronto Star

Illegally overloaded Toronto Transit Commission buses are the major cause of damage to Metro roads, a study obtained by The Star says.

The study, by the Metro roads and traffic department, says the TTC's nearly 1,700 buses, when fully loaded with rush hour crowds, violate the provincial Highway Traffic Act rules governing maximum axle weights.

In the case of a fully loaded bendable bus — the large model used on busier routes — the front-end weight exceeds provincial regulations by 62 per cent, the study found.

The excess weight causes "rutting" that is very expensive to repair, especially in curb lanes and bus bays. And it's a major safety problem, because the ruts cause cars to go out of control.

The damage caused by the buses exceeds $1 million a year, said Tom Johnston, Metro's chief roads maintenance engineer. The department had asked for $35 million from the province for resurfacing and rebuilding of Metro roads this year but the province provided only $25 million.

The ruts are also the cause of the "intolerable nuisance" of pedestrians being splashed by vehicles in curb lanes on rainy days, the study says.

The report calls for drastic measures to be taken, with options ranging from buying a new fleet of buses, limiting passenger loads, changing the law to make TTC buses legal or increasing provincial road repair subsidies.

Yesterday, TTC officials admitted the commission is violating the law with excessive bus weights, but said the problem exists for transit firms in Ottawa, London, Ont. and throughout North America.

"I don't question that our wheel loads exceed the weight limits set out by the (transport) ministry but the ministry knows that," said Don Morton, the TTC's general manager of engineering and maintenance.

"It's not a unique situation either for Toronto or the TTC," he said. He added he's only seen a draft of the study and couldn't comment on it in detail.

Deputy transport minister David Hobbs said he's also familiar with the report, but "it draws certain conclusions we really haven't gotten into in any depth at this point."

The legal maximum for a front axle weight of a bus or truck is 48.9 kilonewtons (a unit of measurement that combines weight and motion) while the bendable buses clock in at 78.3 kilonewtons when fully loaded.

The traditional 40-foot bus also exceeds the provincial maximum, weighing in at 53.3 kilonewtons when loaded.

JOHN MAHLER/TORONTO STAR

CRACKED ROAD: Ruts caused by illegally overloaded TTC buses cost Metro more than $1 million in road repairs and can be a hazard to drivers, a Metro study says.

Appendix B

Detailed Results, Scenario 1 - Vancouver

VANCOUVER BASECASE	PARTICULATE TRAP / LOW SULPHUR FUEL				METHANOL				NATURAL GAS				GASOLINE			
	FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS	
INCREMENTAL PROGRAM COSTS	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.
VEHICLE CAPITAL ('000 $)	$3,407	$2,546	$3,407	$2,288	$11,076	$8,278	$11,076	$7,427	$35,936	$26,888	$35,936	$24,098	($7,488)	($5,596)	($7,488)	($5,021)
INFRASTRUCTURE CAPITAL ('000 $)	$0	$0	$0	$0	$728	$475	$728	$410	$18,860	$12,004	$18,860	$10,227	$450	$330	$450	$293
FUEL ('000 $)	$17,836	$10,022	$14,564	$6,683	$75,996	$42,084	$63,102	$28,323	($50,255)	($29,801)	($9,928)	($8,436)	$100,424	$67,817	$54,989	$25,205
DRIVER WAGES ('000 $)	$3,738	$2,120	$3,738	$1,703	$37,381	$21,198	$37,381	$17,036	$117,303	$66,520	$117,303	$53,459	($17,158)	($9,730)	($17,158)	($7,820)
MAINTENANCE WAGES ('000 $)	$1,582	$839	$1,582	$655	$7,854	$4,145	$7,854	$3,226	$35,341	$18,718	$35,341	$14,597	$1,633	$895	$1,633	$710
PARTS ('000 $)	$885	$469	$885	$366	$5,643	$2,976	$5,643	$2,316	$17,804	$9,396	$17,804	$7,313	$3,696	$1,991	$3,696	$1,566
SALVAGE VALUE ('000 $)	($1,126)	($433)	($1,126)	($291)	($3,940)	($1,516)	($3,940)	($1,018)	($19,634)	($7,887)	($19,634)	($5,074)	($1,023)	($394)	($1,023)	($264)
FLEET COSTS ('000 $)	$26,022	$15,563	$23,050	$11,401	$134,734	$77,639	$121,841	$57,720	$185,354	$96,137	$195,684	$99,184	$80,534	$45,314	$35,099	$14,670
INCREMENTAL PROGRAM IMPACT																
$/PASSENGER	$0.013	$0.008	$0.011	$0.006	$0.066	$0.038	$0.060	$0.028	$0.076	$0.047	$0.096	$0.049	$0.039	$0.022	$0.017	$0.007
'000 $/tonne	$130	$78	$115	$57	($23)	($14)	($21)	($10)	($6)	($4)	($7)	($4)	($9)	($5)	($4)	($2)
$/km	$0.026	$0.015	$0.023	$0.011	$0.115	$0.064	$0.105	$0.048	$0.069	$0.041	$0.119	$0.058	$0.106	$0.061	$0.052	$0.023
$/35,150 kJ (1 LITER OF DIESEL)	$0.011	$0.005	$0.011	$0.004	$0.190	$0.103	$0.176	$0.078	($0.092)	($0.064)	$0.020	$0.001	($0.111)	($0.082)	($0.154)	($0.091)
INCREMENTAL FUEL CONSUMPTION																
CURRENT DIESEL FUEL ('000 l):	(39)				(371)				(1,050)				184			
ALTERNATE FUEL ('000 l):	19,592				421,628				478,739	('000 m3)			142,386			
FLEET DESCRIPTION																
BUSES PURCHASED:	605				649				754				578			
INCREMENTAL FLEET MILAGE																
FLEET MILAGE ('000 km):	4,957				49,977				156,829				(22,939)			
INCREMENTAL EMISSIONS																
HC tonnes	7				187				2,023				(65)			
CO tonnes	12				9,716				796				12,622			
NOx tonnes	48				(3,863)				24,616				(3,481)			
PM tonnes	(267)				(260)				(309)				(314)			
INCREMENTAL EMISSIONS	(200)				5,749				27,126				8,763			

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Appendix C

Detailed Results, Scenario 2 - Vancouver

VANCOUVER HALF FUEL LOAD	PARTICULATE TRAP / LOW SULPHUR FUEL				METHANOL				NATURAL GAS				GASOLINE			
	FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS	
INCREMENTAL PROGRAM COSTS	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.
VEHICLE CAPITAL ('000 $)	$3,343	$2,499	$3,343	$2,242	$5,792	$4,329	$5,792	$3,884	$14,369	$10,740	$14,369	$9,636	($8,836)	($6,604)	($8,836)	($5,925)
INFRASTRUCTURE CAPITAL ('000 $)	$0	$0	$0	$0	$775	$497	$775	$427	$15,725	$10,208	$15,725	$8,879	$500	$328	$500	$283
FUEL ('000 $)	$16,848	$9,628	$13,997	$6,424	$64,476	$35,646	$54,361	$24,407	($88,869)	($34,303)	($19,761)	($9,701)	$93,654	$53,946	$51,056	$23,419
DRIVER WAGES ('000 $)	$3,457	$1,960	$3,457	$1,576	$16,442	$9,324	$16,442	$7,493	$40,622	$23,036	$40,622	$18,513	($21,950)	($12,447)	($21,950)	($10,003)
MAINTENANCE WAGES ('000 $)	$1,547	$821	$1,547	$641	$4,022	$2,128	$4,022	$1,658	$19,628	$10,424	$19,628	$8,141	$136	$104	$156	$94
PARTS ('000 $)	$831	$440	$831	$344	$2,603	$1,373	$2,603	$1,069	$6,581	$3,474	$6,581	$2,704	$2,697	$1,463	$2,697	$1,155
SALVAGE VALUE ('000 $)	($584)	($228)	($584)	($151)	($500)	($193)	($500)	($129)	($9,118)	($3,508)	($9,118)	($2,356)	($2,098)	($808)	($2,098)	($542)
FLEET COSTS ('000 $)	$25,441	$15,125	$22,592	$11,078	$93,610	$53,102	$83,494	$38,808	$29,240	$20,150	$68,049	$35,816	$64,104	$35,983	$21,508	$8,481
INCREMENTAL PROGRAM IMPACT																
$/PASSENGER	$0.012	$0.007	$0.011	$0.005	$0.046	$0.026	$0.041	$0.019	$0.014	$0.010	$0.035	$0.018	$0.031	$0.018	$0.011	$0.004
'000 $/tonne	$130	$78	$116	$57	($19)	($11)	($17)	($8)	($1)	($1)	($3)	($2)	($8)	($4)	($3)	($1)
$/km	$0.026	$0.015	$0.025	$0.011	$0.092	$0.051	$0.082	$0.037	$0.001	$0.002	$0.048	$0.025	$0.094	$0.054	$0.041	$0.018
$/35,150 kJ (1 LITER OF DIESEL)	$0.013	$0.006	$0.013	$0.004	$0.146	$0.078	$0.135	$0.058	($0.189)	($0.119)	($0.083)	($0.047)	($0.118)	($0.086)	($0.160)	($0.093)
INCREMENTAL FUEL CONSUMPTION																
CURRENT DIESEL FUEL ('000 l):	(38)				(176)				(419)				248			
ALTERNATE FUEL ('000 l):	18,777				376,190				395,749	('000 m3)			131,492			
FLEET DESCRIPTION																
BUSES PURCHASED:	586				602				634				552			
INCREMENTAL FLEET MILAGE																
FLEET MILAGE ('000 km):	4,622				21,982				54,310				(29,346)			
INCREMENTAL EMISSIONS																
HC tonnes	7				110				1,565				(72)			
CO tonnes	11				8,879				474				11,968			
NOx tonnes	44				(3,795)				19,624				(3,378)			
PM tonnes	(257)				(255)				(303)				(303)			
INCREMENTAL EMISSIONS	(195)				4,949				21,360				8,214			

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Appendix D

Detailed Results, Scenario 3 - Vancouver

VANCOUVER ZERO WEIGHT PENALTY	PARTICULATE TRAP / LOW SULPHUR FUEL				METHANOL				NATURAL GAS				GASOLINE			
	FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS	
INCREMENTAL PROGRAM COSTS	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.
VEHICLE CAPITAL ('000 $)	$2,556	$1,910	$2,555	$1,713	$2,556	$1,910	$2,556	$1,713	$9,198	$6,875	$9,198	$6,168	($3,577)	($2,673)	($3,577)	($2,399)
INFRASTRUCTURE CAPITAL ('000 $)	$0	$0	$0	$0	$725	$475	$725	$410	$15,675	$10,265	$15,675	$8,862	$626	$409	$626	$353
FUEL ('000 $)	$16,122	$9,220	$13,557	$6,229	$58,805	$32,448	$50,385	$22,622	($66,112)	($38,504)	($26,214)	($12,550)	$109,262	$62,846	$60,533	$27,709
DRIVER WAGES ('000 $)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
MAINTENANCE WAGES ('000 $)	$849	$453	$849	$355	$611	$326	$611	$256	$9,856	$5,262	$9,856	$4,121	$5,098	$2,722	$5,098	$2,131
PARTS ('000 $)	$341	$182	$341	$142	$233	$124	$233	$97	$681	$364	$681	$285	$6,381	$3,407	$6,381	$2,668
SALVAGE VALUE ('000 $)	($844)	($526)	($844)	($218)	($1,125)	($433)	($1,125)	($291)	($9,100)	($3,503)	($9,100)	($2,352)	($411)	($158)	($411)	($106)
FLEET COSTS ('000 $)	$19,022	$11,440	$16,457	$8,221	$61,805	$34,850	$53,384	$24,807	($39,802)	($19,241)	$96	$4,534	$117,379	$66,553	$68,650	$30,356
INCREMENTAL PROGRAM IMPACT																
$/PASSENGER	$0.009	$0.006	$0.008	$0.004	$0.050	$0.017	$0.026	$0.012	($0.020)	($0.009)	$0.000	$0.002	$0.058	$0.033	$0.034	$0.015
'000 $/tonne	$72	$43	$62	$31	($13)	($8)	($12)	($5)	$2	$1	($0)	($0)	($12)	($7)	($7)	($3)
$/km	$0.021	$0.013	$0.018	$0.009	$0.069	$0.039	$0.060	$0.028	($0.045)	($0.022)	$0.000	$0.005	$0.132	$0.075	$0.077	$0.034
$/38,150 kJ (1 LITER OF DIESEL)	$0.002	($0.000)	$0.002	($0.000)	$0.101	$0.054	$0.087	$0.038	($0.267)	($0.159)	($0.163)	($0.080)	($0.073)	($0.062)	($0.116)	($0.074)
INCREMENTAL FUEL CONSUMPTION																
CURRENT DIESEL FUEL ('000 l):	0				0				0				0			
ALTERNATE FUEL ('000 l):	16,866				361,163				369,359	('000 m3)			158,821			
FLEET DESCRIPTION																
BUSES PURCHASED:	596				596				596				596			
INCREMENTAL FLEET MILAGE																
FLEET MILAGE ('000 km):	0				0				0				0			
INCREMENTAL EMISSIONS																
HC tonnes	0				77				1,388				(33)			
CO tonnes	0				8,721				321				13,117			
NOx tonnes	0				(3,948)				17,829				(3,373)			
PM tonnes	(265)				(265)				(315)				(310)			
INCREMENTAL EMISSIONS	(265)				4,584				19,222				9,401			

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Appendix E

Detailed Results, Scenario 4 - Vancouver

VANCOUVER BASECASE RESEARCH ENGINE	PARTICULATE TRAP / LOW SULPHUR FUEL				METHANOL				NATURAL GAS				GASOLINE			
	FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS	
INCREMENTAL PROGRAM COSTS	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.
VEHICLE CAPITAL ('000 $)	$3,407	$2,546	$3,407	$2,285	$11,076	$8,278	$11,076	$7,427	$38,187	$28,641	$38,187	$25,608	($7,488)	($5,696)	($7,488)	($5,021)
INFRASTRUCTURE CAPITAL ('000 $)	$0	$0	$0	$0	$725	$475	$725	$410	$18,860	$12,004	$18,860	$10,227	$480	$330	$450	$293
FUEL ('000 $)	$17,536	$10,022	$14,564	$6,683	$65,901	$36,381	$55,680	$24,962	($48,868)	($29,038)	($8,533)	($4,826)	$100,424	$57,817	$54,989	$25,205
DRIVER WAGES ('000 $)	$3,738	$2,120	$3,738	$1,703	$37,381	$21,198	$37,381	$17,036	$127,181	$72,122	$127,181	$57,962	($17,188)	($9,730)	($17,158)	($7,820)
MAINTENANCE WAGES ('000 $)	$1,582	$839	$1,582	$655	$7,854	$4,145	$7,854	$3,226	$37,482	$19,849	$37,482	$15,478	$1,633	$898	$1,633	$710
PARTS ('0U0 $)	$885	$469	$885	$366	$5,643	$2,976	$5,643	$2,316	$19,248	$10,158	$19,248	$7,906	$3,696	$1,991	$3,696	$1,566
SALVAGE VALUE ('000 $)	($1,126)	($433)	($1,126)	($291)	($3,940)	($1,516)	($3,940)	($1,018)	($20,378)	($7,843)	($20,378)	($5,266)	($1,023)	($394)	($1,023)	($264)
FLEET COSTS ('000 $)	$26,022	$15,563	$23,050	$11,401	$124,640	$71,937	$114,418	$54,359	$171,713	$105,793	$212,048	$107,088	$80,534	$45,314	$35,099	$14,670
INCREMENTAL PROGRAM IMPACT																
$/PASSENGER	$0.013	$0.008	$0.011	$0.006	$0.061	$0.035	$0.056	$0.027	$0.084	$0.052	$0.104	$0.082	$0.039	$0.022	$0.017	$0.007
'000 $/tonne	$130	$78	$115	$57	$33	$19	$30	$14	($62)	($38)	($76)	($38)	($9)	($5)	($4)	($2)
$/km	$0.026	$0.015	$0.023	$0.011	$0.104	$0.058	$0.097	$0.045	$0.077	$0.045	$0.127	$0.062	$0.106	$0.061	$0.052	$0.023
$/35,150 kJ (1 LITER OF DIESEL)	$0.011	$0.005	$0.011	$0.004	$0.210	$0.117	$0.196	$0.090	($0.080)	($0.067)	$0.033	$0.006	($0.111)	($0.082)	($0.154)	($0.091)
INCREMENTAL FUEL CONSUMPTION																
CURRENT DIESEL FUEL ('000 l):	(39)				(371)				(1,125)				184			
ALTERNATE FUEL ('000 l):	19,592				387,250				487,665	('000 m3)			142,386			
FLEET DESCRIPTION																
BUSES PURCHASED:	605				649				767				578			
INCREMENTAL FLEET MILAGE																
FLEET MILAGE ('000 km):	4,997				49,977				170,037				(22,939)			
INCREMENTAL EMISSIONS																
HC tonnes	7				(111)				1,535				(65)			
CO tonnes	12				(836)				(1,084)				12,622			
NOx tonnes	48				(2,573)				2,602				(3,481)			
PM tonnes	(267)				(260)				(271)				(314)			
INCREMENTAL EMISSIONS	(200)				(3,779)				2,782				8,763			

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Appendix F

Detailed Results, Scenario 5 - Vancouver

VANCOUVER HALF FUEL LOAD RESEARCH ENGINE	PARTICULATE TRAP / LOW SULPHUR FUEL				METHANOL				NATURAL GAS				GASOLINE			
	FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS	
INCREMENTAL PROGRAM COSTS	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.
VEHICLE CAPITAL ('000 $)	$3,343	$2,499	$3,343	$2,242	$5,792	$4,329	$5,792	$3,884	$15,881	$11,870	$15,881	$10,650	($8,836)	($6,604)	($8,836)	($5,925)
INFRASTRUCTURE CAPITAL ('000 $)	$0	$0	$0	$0	$775	$497	$775	$427	$15,726	$10,288	$15,726	$8,879	$500	$328	$500	$283
FUEL ('000 $)	$16,845	$9,628	$13,997	$6,424	$55,192	$30,400	$47,534	$21,314	($57,641)	($33,793)	($18,827)	($9,293)	$93,684	$53,946	$51,056	$23,419
DRIVER WAGES ('000 $)	$3,457	$1,960	$3,457	$1,576	$16,442	$9,324	$16,442	$7,493	$47,255	$26,798	$47,255	$21,536	($21,950)	($12,447)	($21,950)	($10,005)
MAINTENANCE WAGES ('000 $)	$1,547	$821	$1,547	$641	$4,022	$2,128	$4,022	$1,655	$21,173	$11,241	$21,173	$8,776	$136	$104	$136	$94
PARTS ('000 $)	$831	$440	$831	$344	$2,603	$1,373	$2,603	$1,069	$7,548	$3,984	$7,548	$3,101	$2,697	$1,463	$2,697	$1,185
SALVAGE VALUE ('000 $)	($584)	($225)	($584)	($151)	($800)	($193)	($800)	($129)	($9,615)	($3,701)	($9,615)	($2,486)	($2,098)	($808)	($2,098)	($542)
FLEET COSTS ('000 $)	$25,441	$15,125	$22,592	$11,075	$84,325	$47,856	$76,668	$35,713	$40,327	$26,686	$79,141	$41,164	$64,104	$35,983	$21,505	$8,481
INCREMENTAL PROGRAM IMPACT																
$/PASSENGER	$0.012	$0.007	$0.011	$0.005	$0.041	$0.023	$0.038	$0.018	$0.020	$0.013	$0.039	$0.020	$0.031	$0.018	$0.011	$0.004
'000 $/tonne	$130	$78	$116	$57	$22	$13	$20	$9	($54)	($22)	($66)	($34)	($8)	($4)	($3)	($1)
$/km	$0.026	$0.015	$0.023	$0.011	$0.081	$0.045	$0.075	$0.034	$0.008	$0.006	$0.055	$0.028	$0.094	$0.054	$0.041	$0.018
$/35,150 kJ (1 LITER OF DIESEL)	$0.013	$0.006	$0.013	$0.004	$0.163	$0.090	$0.150	$0.068	($0.178)	($0.113)	($0.071)	($0.042)	($0.118)	($0.086)	($0.160)	($0.095)
INCREMENTAL FUEL CONSUMPTION																
CURRENT DIESEL FUEL ('000 l):	(38)				(176)				(483)				248			
ALTERNATE FUEL ('000 l):	18,777				344,569				401,761	('000 m3)			131,492			
FLEET DESCRIPTION																
BUSES PURCHASED:	585				602				645				552			
INCREMENTAL FLEET MILAGE																
FLEET MILAGE ('000 km):	4,622				21,982				63,179				(29,346)			
INCREMENTAL EMISSIONS																
HC tonnes	7				(136)				1,155				(72)			
CO tonnes	11				(826)				(1,081)				11,968			
NOx tonnes	44				(2,598)				1,402				(3,378)			
PM tonnes	(267)				(256)				(273)				(303)			
INCREMENTAL EMISSIONS	(195)				(3,815)				1,204				8,214			

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Appendix G

Detailed Results, Scenario 6 - Vancouver

VANCOUVER ZERO WEIGHT PENALTY RESEARCH ENGINE	PARTICULATE TRAP / LOW SULPHUR FUEL				METHANOL				NATURAL GAS				GASOLINE			
	FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS	
INCREMENTAL PROGRAM COSTS	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.
VEHICLE CAPITAL ('000 $)	$2,555	$1,910	$2,555	$1,713	$2,555	$1,910	$2,555	$1,713	$9,198	$6,878	$9,198	$6,168	($3,577)	($2,673)	($3,577)	($2,399)
INFRASTRUCTURE CAPITAL ('000 $)	$0	$0	$0	$0	$728	$478	$725	$410	$15,675	$10,268	$15,675	$8,862	$625	$409	$625	$353
FUEL ('000 $)	$16,122	$9,220	$13,557	$6,229	$49,632	$27,264	$43,639	$19,866	($66,112)	($38,804)	($25,214)	($12,880)	$109,262	$62,046	$60,533	$27,709
DRIVER WAGES ('000 $)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
MAINTENANCE WAGES ('000 $)	$849	$453	$849	$355	$611	$326	$611	$256	$9,856	$5,262	$9,856	$4,121	$5,098	$2,722	$5,098	$2,131
PARTS ('000 $)	$341	$182	$341	$142	$233	$124	$233	$97	$681	$364	$681	$285	$6,381	$3,407	$6,381	$2,668
SALVAGE VALUE ('000 $)	($844)	($525)	($844)	($218)	($1,125)	($433)	($1,125)	($291)	($9,100)	($3,803)	($9,100)	($2,352)	($411)	($158)	($411)	($106)
FLEET COSTS ('000 $)	$19,022	$11,440	$16,457	$8,221	$52,631	$29,666	$46,639	$21,752	($39,802)	($19,241)	$96	$4,834	$117,379	$66,553	$68,650	$30,358
INCREMENTAL PROGRAM IMPACT																
$/PASSENGER	$0.009	$0.006	$0.008	$0.004	$0.026	$0.015	$0.023	$0.011	($0.020)	($0.009)	$0.000	$0.002	$0.058	$0.033	$0.034	$0.015
'000 $/tonne	$72	$43	$62	$31	$13	$7	$11	$5	$138	$67	($0)	($16)	($12)	($7)	($7)	($3)
$/km	$0.021	$0.013	$0.018	$0.009	$0.059	$0.033	$0.052	$0.024	($0.048)	($0.022)	$0.000	$0.005	$0.132	$0.075	$0.077	$0.034
$/35,150 kJ (1 LITER OF DIESEL)	$0.002	($0.000)	$0.002	($0.000)	$0.117	$0.066	$0.104	$0.048	($0.267)	($0.159)	($0.163)	($0.080)	($0.073)	($0.062)	($0.116)	($0.074)
INCREMENTAL FUEL CONSUMPTION																
CURRENT DIESEL FUEL ('000 l):	0				0				0				0			
ALTERNATE FUEL ('000 l):	16,866				329,918				369,389	('000 m3)			188,821			
FLEET DESCRIPTION																
BUSES PURCHASED:	596				596				596				596			
INCREMENTAL FLEET MILAGE																
FLEET MILAGE ('000 km):	0				0				0				0			
INCREMENTAL EMISSIONS																
HC tonnes	0				(166)				979				(33)			
CO tonnes	0				(868)				(1,154)				13,117			
NOx tonnes	0				(2,776)				750				(3,373)			
PM tonnes	(265)				(266)				(288)				(310)			
INCREMENTAL EMISSIONS	(265)				(4,076)				288				9,401			

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Appendix H

Detailed Results, Scenario 6: Edmonton, Hamilton, Toronto, Montreal

TORONTO ZERO WEIGHT PENALTY, RESEARC	PARTICULATE TRAP / LOW SULPHUR FUEL				METHANOL				NATURAL GAS				GASOLINE			
	FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS	
INCREMENTAL PROGRAM COSTS	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.
VEHICLE CAPITAL ('000 $)	$7,625	$5,432	$7,625	$4,779	$7,625	$5,432	$7,625	$4,779	$27,450	$19,554	$27,450	$17,205	($10,675)	($7,604)	($10,675)	($6,691)
INFRASTRUCTURE CAPITAL ('000 $)	$0	$0	$0	$0	$1,596	$1,038	$1,596	$888	$34,485	$22,441	$34,485	$19,191	$1,375	$898	$1,375	$765
FUEL ('000 $)	$42,712	$23,910	$57,744	$25,674	$177,090	$95,781	$228,132	$100,410	*********	($87,013)	($41,178)	($18,909)	$209,138	$118,160	$137,484	$60,810
DRIVER WAGES ('000 $)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
MAINTENANCE WAGES ('000 $)	$1,416	$670	$1,416	$491	$809	$551	$809	$243	$3,440	$1,734	$3,440	$1,318	$5,546	$2,841	$5,546	$2,179
PARTS ('000 $)	$873	$459	$873	$507	$597	$514	$597	$244	$1,746	$918	$1,746	$714	$10,798	$5,677	$10,798	$4,414
SALVAGE VALUE ('000 $)	($2,477)	($1,049)	($2,477)	($733)	($3,077)	($1,303)	($3,077)	($910)	($21,876)	($9,263)	($21,876)	($6,472)	($1,012)	($429)	($1,012)	($299)
FLEET COSTS ('000 $)	$50,149	$29,422	$65,182	$30,868	$184,640	$101,613	$235,682	$105,654	*********	($51,629)	$4,067	$13,046	$215,170	$119,541	$143,516	$61,177
INCREMENTAL PROGRAM IMPACT																
$/PASSENGER	$0.006	$0.004	$0.008	$0.004	$0.022	$0.012	$0.029	$0.015	($0.013)	($0.006)	$0.000	$0.002	$0.026	$0.018	$0.017	$0.007
'000 $/tonne	$69	$40	$90	$42	$17	$9	$21	$10	$136	$66	($5)	($17)	($8)	($5)	($6)	($2)
$/km	$0.022	$0.013	$0.028	$0.013	$0.080	$0.044	$0.102	$0.046	($0.046)	($0.022)	$0.002	$0.006	$0.093	$0.062	$0.062	$0.026
$/35,150 kJ (1 LITER OF DIESEL)	$0.003	($0.001)	$0.020	$0.007	$0.148	$0.081	$0.191	$0.085	($0.252)	($0.151)	($0.150)	($0.074)	($0.123)	($0.092)	($0.129)	($0.081)
INCREMENTAL FUEL CONSUMPTION																
CURRENT DIESEL FUEL ('000 l):	0				0				0				0			
ALTERNATE FUEL ('000 l):	45,748				893,982				********* ('000 m3)				450,482			
FLEET DESCRIPTION																
BUSES PURCHASED:	1,825				1,825				1,825				1,825			
INCREMENTAL FLEET MILAGE																
FLEET MILAGE ('000 km):	0				0				0				0			
INCREMENTAL EMISSIONS																
HC tonnes	0				(448)				2,658				(98)			
CO tonnes	0				(2,364)				(3,078)				35,535			
NOx tonnes	0				(7,527)				1,987				(9,136)			
PM tonnes	(727)				(714)				(783)				(853)			
INCREMENTAL EMISSIONS	(727)				(11,052)				783				25,448			

DATE: 09/18
TIME: 11:18 AM

MONTREAL ZERO WEIGHT PENALTY, RESEARC	PARTICULATE TRAP / LOW SULPHUR FUEL				METHANOL				NATURAL GAS				GASOLINE			
	FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS	
INCREMENTAL PROGRAM COSTS	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.
VEHICLE CAPITAL ('000 $)	$10,306	$8,167	$10,306	$7,480	$10,306	$8,167	$10,305	$7,480	$37,098	$29,402	$37,098	$26,926	($14,427)	($11,434)	($14,427)	($10,471)
INFRASTRUCTURE CAPITAL ('000 $)	$0	$0	$0	$0	$2,465	$1,689	$2,465	$1,448	$53,298	$35,878	$53,298	$31,238	$2,125	$1,430	$2,125	$1,246
FUEL ('000 $)	$27,049	$14,167	$23,384	$9,428	$144,826	$74,548	$120,848	$48,400	($85,468)	($45,517)	($27,710)	($11,416)	$146,787	$77,476	$78,509	$31,607
DRIVER WAGES ('000 $)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
MAINTENANCE WAGES ('000 $)	$1,327	$658	$1,327	$497	$956	$474	$956	$358	$2,681	$1,330	$2,681	$1,004	$4,061	$2,014	$4,061	$1,520
PARTS ('000 $)	$597	$296	$597	$224	$409	$203	$409	$183	$1,194	$592	$1,194	$447	$7,386	$3,664	$7,386	$2,765
SALVAGE VALUE ('000 $)	($2,121)	($988)	($2,121)	($719)	($3,001)	($1,398)	($3,001)	($1,017)	($26,656)	($12,418)	($26,656)	($9,029)	($1,185)	($551)	($1,185)	($401)
FLEET COSTS ('000 $)	$37,157	$22,301	$33,492	$16,910	$155,959	$83,683	$131,981	$56,819	($17,855)	$9,264	$39,905	$39,170	$144,749	$72,599	$76,471	$26,267
INCREMENTAL PROGRAM IMPACT																
$/PASSENGER	$0.006	$0.004	$0.006	$0.003	$0.027	$0.014	$0.023	$0.010	($0.005)	$0.002	$0.007	$0.007	$0.025	$0.012	$0.013	$0.004
'000 $/tonne	$83	$50	$75	$38	$23	$12	$19	$8	$38	($19)	($84)	($82)	($9)	($5)	($5)	($2)
$/km	$0.021	$0.013	$0.019	$0.010	$0.088	$0.047	$0.074	$0.032	($0.010)	$0.005	$0.022	$0.022	$0.081	$0.041	$0.043	$0.015
$/35,150 kJ (1 LITER OF DIESEL)	$0.006	$0.002	$0.006	$0.002	$0.140	$0.075	$0.118	$0.051	($0.183)	($0.084)	($0.088)	($0.036)	($0.096)	($0.080)	($0.119)	($0.079)
INCREMENTAL FUEL CONSUMPTION																
CURRENT DIESEL FUEL ('000 l):	0				0				0				0			
ALTERNATE FUEL ('000 l):	28,145				549,611				615,263	('000 m3)			264,669			
FLEET DESCRIPTION																
BUSES PURCHASED:	2,146				2,146				2,146				2,146			
INCREMENTAL FLEET MILAGE																
FLEET MILAGE ('000 km):	0				0				0				0			
INCREMENTAL EMISSIONS																
HC tonnes	0				(273)				1,634				(52)			
CO tonnes	0				(1,456)				(1,894)				21,848			
NOx tonnes	0				(4,627)				1,218				(5,622)			
PM tonnes	(446)				(446)				(483)				(520)			
INCREMENTAL EMISSIONS	(446)				(6,802)				475				15,654			

DATE: 09/18
TIME: 11:12 AM

EDMONTON ZERO WEIGHT PENALTY, RESEARCH ENGINE	PARTICULATE TRAP / LOW SULPHUR FUEL				METHANOL				NATURAL GAS				GASOLINE			
	FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS	
INCREMENTAL PROGRAM COSTS	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.
VEHICLE CAPITAL ('000 $)	$2,920	$2,077	$2,920	$1,820	$2,920	$2,077	$2,920	$1,820	$10,512	$7,478	$10,512	$6,582	($4,088)	($2,908)	($4,088)	($2,548)
INFRASTRUCTURE CAPITAL ('000 $)	$0	$0	$0	$0	$580	$404	$580	$384	$12,540	$8,734	$12,540	$7,649	$500	$348	$500	$305
FUEL ('000 $)	$6,653	$3,312	$6,026	$2,255	$20,649	$10,224	$22,640	$8,463	($24,514)	($12,261)	($14,507)	($5,468)	$37,942	$18,932	$25,275	$9,465
DRIVER WAGES ('000 $)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
MAINTENANCE WAGES ('000 $)	$347	$167	$347	$124	$250	$120	$250	$89	$701	$338	$701	$251	$1,061	$511	$1,061	$380
PARTS ('000 $)	$145	$70	$145	$52	$99	$48	$99	$35	$290	$140	$290	$104	$1,792	$865	$1,792	$641
SALVAGE VALUE ('000 $)	($1,092)	($420)	($1,092)	($282)	($1,256)	($483)	($1,256)	($325)	($7,482)	($2,880)	($7,482)	($1,934)	($360)	($139)	($360)	($93)
FLEET COSTS ('000 $)	$8,975	$5,206	$8,346	$3,969	$23,242	$12,390	$25,233	$10,457	($7,954)	$1,548	$2,053	$7,184	$36,847	$17,608	$24,180	$8,149
INCREMENTAL PROGRAM IMPACT																
$/PASSENGER	$0.011	$0.006	$0.010	$0.005	$0.028	$0.015	$0.030	$0.012	($0.010)	$0.002	$0.002	$0.009	$0.044	$0.021	$0.029	$0.010
'000 $/tonne	$75	$44	$70	$33	$13	$7	$14	$6	$61	($12)	($16)	($55)	($9)	($4)	($6)	($2)
$/km	$0.015	$0.009	$0.014	$0.007	$0.038	$0.020	$0.042	$0.017	($0.013)	$0.003	$0.003	$0.012	$0.061	$0.029	$0.040	$0.013
$/35,150 kJ (1 LITER OF DIESEL)	$0.004	$0.001	$0.005	$0.001	$0.068	$0.036	$0.074	$0.031	($0.134)	($0.069)	($0.096)	($0.057)	($0.074)	($0.064)	($0.090)	($0.065)
INCREMENTAL FUEL CONSUMPTION																
CURRENT DIESEL FUEL ('000 l):	0				0				0				0			
ALTERNATE FUEL ('000 l):	7,660				149,818				167,722	('000 m3)			72,132			
FLEET DESCRIPTION																
BUSES PURCHASED:	669				669				669				669			
INCREMENTAL FLEET MILAGE																
FLEET MILAGE ('000 km):	0				0				0				0			
INCREMENTAL EMISSIONS																
HC tonnes	0				(73)				446				(14)			
CO tonnes	0				(397)				(516)				5,956			
NOx tonnes	0				(1,259)				353				(1,530)			
PM tonnes	(119)				(119)				(131)				(142)			
INCREMENTAL EMISSIONS.	(119)				(1,849)				131				4,271			

DATE: 09/18
TIME: 09:44 AM

HAMILTON ZERO WEIGHT PENALTY, RESEARCH ENGINE	PARTICULATE TRAP / LOW SULPHUR FUEL				METHANOL				NATURAL GAS				GASOLINE			
	FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS		FINANCIAL ANALYSIS		ECONOMIC ANALYSIS	
INCREMENTAL PROGRAM COSTS	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.	1989 $	N.P.V.
VEHICLE CAPITAL ('000 $)	$1,146	$839	$1,146	$751	$1,146	$839	$1,146	$751	$4,122	$3,019	$4,122	$2,705	($1,603)	($1,174)	($1,603)	($1,062)
INFRASTRUCTURE CAPITAL ('000 $)	$150	$96	$150	$82	$583	$372	$583	$319	$9,588	$6,077	$9,555	$5,210	$526	$534	$526	$286
FUEL ('000 $)	$1,699	$963	$1,471	$664	$7,027	$3,866	$8,248	$3,692	($6,089)	($3,508)	($2,467)	($1,136)	$8,338	$4,765	$4,648	$2,090
DRIVER WAGES ('000 $)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
MAINTENANCE WAGES ('000 $)	$79	$42	$79	$33	$57	$30	$57	$24	$241	$128	$241	$100	$241	$128	$241	$100
PARTS ('000 $)	$33	$18	$33	$14	$24	$13	$24	$10	$427	$228	$427	$178	$427	$228	$427	$178
SALVAGE VALUE ('000 $)	($438)	($186)	($438)	($130)	($641)	($272)	($641)	($190)	($5,788)	($2,450)	($5,785)	($1,712)	($319)	($138)	($319)	($94)
FLEET COSTS ('000 $)	$2,669	$1,772	$2,441	$1,418	$8,196	$4,848	$9,417	$4,606	$2,501	$3,497	$6,093	$5,345	$7,609	$4,146	$3,919	$1,500
INCREMENTAL PROGRAM IMPACT																
$/PASSENGER	$0.005	$0.003	$0.005	$0.003	$0.016	$0.009	$0.018	$0.009	$0.005	$0.007	$0.012	$0.010	$0.015	$0.008	$0.008	$0.003
'000 $/tonne	$93	$62	$85	$49	$19	$11	$21	$11	($80)	($112)	($195)	($171)	($8)	($4)	($4)	($1)
$/km	$0.012	$0.008	$0.011	$0.007	$0.038	$0.023	$0.044	$0.021	$0.012	$0.016	$0.028	$0.025	$0.035	$0.019	$0.018	$0.007
$/35,150 kJ (1 LITER OF DIESEL)	$0.006	$0.004	$0.006	$0.004	$0.064	$0.038	$0.074	$0.036	($0.060)	($0.025)	($0.023)	$0.003	($0.064)	($0.047)	($0.075)	($0.045)
INCREMENTAL FUEL CONSUMPTION																
CURRENT DIESEL FUEL ('000 l):	0				0				0				0			
ALTERNATE FUEL ('000 l):	1,817				35,827				39,765	('000 m3)			17,106			
FLEET DESCRIPTION																
BUSES PURCHASED:	314				314				314				314			
INCREMENTAL FLEET MILAGE																
FLEET MILAGE ('000 km):	0				0				0				0			
INCREMENTAL EMISSIONS																
HC tonnes	0				(17)				106				(3)			
CO tonnes	0				(93)				(122)				1,412			
NOx tonnes	0				(299)				79				(363)			
PM tonnes	(29)				(29)				(31)				(34)			
INCREMENTAL EMISSIONS	(29)				(438)				31				1,012			

DATE: 09/18
TIME: 10:19 AM